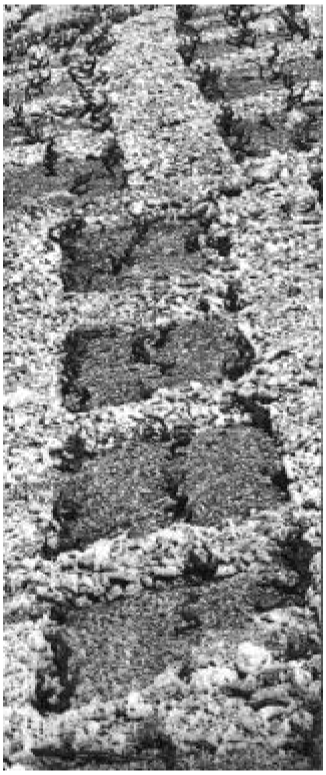

PRIORITY ACTIONS PROGRAMME

MEDITERRANEAN ACTION PLAN

UNEP

in cooperation with

FAO

GUIDELINES

for mapping and measurement of rainfall-induced erosion processes in the Mediterranean coastal areas

PRIORITY ACTIONS PROGRAMME
REGIONAL ACTIVITY CENTRE
SPLIT, 1997

Note: This document was prepared by the Priority Actions Programme Regional Activity Centre (PAP/RAC) of the Mediterranean Action Plan, UNEP, in collaboration with the General Directorate for the Conservation of the Nature (Dirección General de Conservacion de la Naturaleza - DGCONA) of the Spanish Ministry of Environment and the Land and Water Development Division (AGL) of the Food and Agriculture Organization of the United Nations (FAO). The authors of the document are: J.C. Griesbach, J.D. Ruiz Sinoga, A. Giordano, O. Berney, F. Gallart, and L. Rojo Serrano. Mr. A. Pavasovic, former director of PAP/RAC, contributed in the conception of the document and the revision of its draft version, and prepared the Annex I related to integrated coastal management.

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PREFACE

These Guidelines have been prepared on the basis of the results of the Cooperative Project "Mapping and Measurement of Rainfall-Induced Erosion Processes in the Mediterranean Coastal Areas", implemented by the Priority Actions Programme of the Mediterranean Action Plan, UNEP, and the General Directorate for the Conservation of the Nature (DGCONA) Madrid, in cooperation with the Food and Agriculture Organization of the United Nations (FAO).

One of the main reasons for implementing the co-operative project lay in the fact that the hitherto practice on mapping and measurement of erosion processes in the Mediterranean coastal areas involved a number of different, often incomparable methodologies and procedures. Therefore, the need was felt to develop a consolidated methodology to be tested through case studies and eventually adopted for general use.

The project was implemented in two components: the first one, dedicated to mapping, was implemented during the 1991-1992 period (the Vallcebre mapping in 1995-96), and the second one, dedicated to measurement, in the period 1993-1996. The mapping component was supported by mapping exercises for the areas of Adra and Vallcebre (Spain), Essen (Turkey) and Oued Ermel (Tunisia). The measurement component was supported by pilot measurements of erosion processes performed in the areas of Vallcebre (Spain), Caybogazi (Turkey), and El Khairat (Tunisia). The results of these exercises were presented by national expert teams within relevant national reports (see PAP/RAC-UNEP,1997).

On the basis of the achieved results a draft version of the Guidelines was prepared and presented at a workshop held in Barcelona on 13-16 October 1996. Their final version was prepared on the basis of recommendations and amendments proposed by the workshop.

The objectives of the Guidelines are:

- to contribute to a better management of soils and other natural resources and to the mitigation of erosion in the Mediterranean coastal areas;
- to present the methodology, basis and prerequisites for mapping and measurement of erosion processes in the region; and
- to give basic instructions for performing mapping and measurement.

These Guidelines are primarily intended for the following audience:

- experts in soil erosion and hydrology with certain experience in erosion mapping and/or measurement for practical use;
- professionals in land-use planning and management, soil management, agriculture and other fields - for information and general knowledge, while additional training would be needed for implementation;
- decision-makers in related fields - for information and understanding of their involvement and responsibilities (in particular the Executive Summary, Part I: Chapters 1, 2.1 and 4; Part II: Chapter 1; Conclusions; and Annex I).

Due to the complex nature of the erosion phenomena and their implications on the measurement process, practice may show that during the application of the developed methodology, in some areas, need may arise for consultation with FAO, DGCONA or PAP-MAP.

These Guidelines have to be understood as a framework document, whose use is not obligatory and might request a flexible approach with adaptation in specific conditions.

The methodology presented is applicable not only for rainfall-induced erosion processes as stated in the title, but considers also wind erosion and other degradation processes induced by land management.

The results achieved and lessons learned from the exercises presented in national reports confirm the flexibility and adaptability of the mapping and measurement methods as applied in four different types of catchments in Mediterranean coastal areas.

Although the Guidelines were conceived and tested in the Mediterranean region, it is likely that they can be applied, with some adaptation if necessary, in other regions of the world.

EXECUTIVE SUMMARY

The present Guidelines are one of the outputs of a co-operative effort of PAP/MAP/UNEP, Ministry of Environment/ DGCONA (Madrid), and FAO/AGL, as well as of professional institutions and authorities of Spain, Tunisia and Turkey, relative to the mapping and measurement of rainfall-induced soil erosion process in the region.

The document is intended for:

- experts, professionals and institutions involved in erosion control in the region, for practical application;
- professionals in land use, soil management, water resources management, agriculture and other relevant sectors, for information and general knowledge (additional training would be needed for implementation);
- decision makers in related fields, for information and understanding of their role and responsibilities (in particular: Executive Summary, Part I: Chapters 1, 2.1 and 4, Part II: Chapters 1, 5 and 6, and Annex I); and
- experts, institutions and decision makers involved in Integrated Coastal Area Management (ICAM) in the region (in particular: Executive Summary, Part I: Chapters 1, 2.1, Part II: Chapter 1, and Annex I) for a better understanding of the impacts of erosion on the economy, social conditions and environment, and of the role of erosion mapping and measurement within ICAM.

Soil erosion processes in the Mediterranean coastal areas have serious consequences for rational use of resources and the coastal environment. The fragility of Mediterranean eco-systems, the permanently increasing coastal population, the importance of Mediterranean agriculture and need for higher productivity, and the increased pollution require a comprehensive assessment and evaluation of the erosion phenomena. Mapping and measurement of erosion in affected areas provides the basis for the design and implementation of erosion control and soil management programmes which should be integrated within the ICAM scheme as a broader framework.

With regard to the above, the Mediterranean coastal states, in their role of Contracting Parties to the Barcelona Convention and participants in the Mediterranean Action Plan (MAP), entrusted the Priority Actions Programme (PAP) of MAP with the implementation of a priority action dedicated to "Soil Protection as an Essential Component of the Protection of the Mediterranean Environment". After several years of implementation (1984-1988), that action was focused on rainfall-induced erosion processes. The fact finding phase indicated that, unfortunately, the erosion control activities within countries were based on a number of different mapping and measurement methodologies, most of which incomparable with the others. Therefore, a co-operative PAP-FAO-DGCONA project was formulated and implemented with the participation of Spain, Tunisia and Turkey. The mapping component was implemented in the 1991-1992 period, with some additional mapping performed in 1995-96, with 3 national pilot mappings and the Part I of the Guidelines as principal outputs. The measurement component was implemented in the 1993-1995 period with 3 experimental erosion measurements in selected areas in Spain, Tunis and Turkey, and the Part II of the Guidelines, as principal outputs.

In the **introductory part of the Guidelines,** the common types of rainfall-induced erosion phenomena with particular reference to Mediterranean conditions are presented, as well as links between mapping and measurement and the process of integrated coastal management.

In the **Part I**, a common consolidated methodology for mapping of rainfall-induced soil erosion processes in the Mediterranean coastal areas is presented. This methodology has an innovative character. Namely, it allows the presentation of both erosion status and dynamics in a single integrated map. Compared to traditional mapping systems, such an output shows great advantages for erosion control processes and ICAM. According to the common consolidated mapping methodology, the mapping process consists of three phases:

a) **Predictive** mapping by identifying, assessing and integrating all basic parameters, such as physiography (slopes), lithology and/or soils, land, and vegetation cover, in view of determining preliminary assumptions on erosion risks (erodibility - potential erosion);

b) **Descriptive** mapping when describing and qualitatively assessing current on-site and active erosion processes. This systematic mapping of qualitative and dynamic erosion features identifies two broad categories of geographic environments: geographically stable, non-erosion affected areas on the one hand, and unbalanced, erosion-affected areas on the other.

c) The **consolidation** and **integration** phase, which provides the final cartographic product identifying and assessing both the erosion potential (erosion status) and current erosion process, intensities and trends.

The mapping process is described in detail, and maps relevant to each step are included.

In the **Part II**, general methods of erosion measurement are presented and commented as a basis for the design of specific measurement activities that should be necessarily adapted to the conditions and particular objectives of each country or sub-region.

A specific, recommended measurement programme and data processing framework is presented in full detail to serve as guide for the implementation of measurement projects in the Mediterranean coastal areas.

The adopted scheme recommends the inclusion into the measurement programme of a group of at least three adjacent catchments of different sizes, up to 20 km^2. Some of the smaller catchements should be contained within the larger ones to understand the rules of scale change in sediment transport processes, what is of critical importance for the assessing of erosion impacts in coastal areas. Precise instructions are given about the selection of the catchments and the selection of the measuring points.

Catchment instrumentation is composed of the following elements:

- *Runoff control structure*. Flume or weir according the circumstances of bed-load transport of the flow.
- *Data logger*. Two counting channels.
- *Water level sensor*. An electronic device to convert water level in an electronic impulse. Directly readable by the data logger. Capacitive sensor device is recommended for semi-arid conditions.
- *Suspended sediment sampling instrument*. Two simultaneous systems recommended:
  a) a programmable pumping water instrument triggered by the data logger or other water level threshold triggering mechanism;
  b) A syphon sampling device, consisting on a series of bottles at different heights, which takes water samples at various water levels as the hydrograph rises
- *Rainfall recording stations*. A minimum of one rain recorder per hydrometric station. Tipping bucket mechanism pluviometers connected to data logger recommended.

Field visits programme and laboratory determinations are also thoroughly described.

Data processing and implementation is of critical importance for the success of the measurement programme. The potential sources of error, the procedures for interpolation and extrapolation and the event analysis and temporal integration, receive preferential attention.

Data processing steps, as well as the procedures for numerical and graphical presentation of data, are described using the more common, standard, hardware resources and software tools available, as data base management programmes, spreadsheets and integrated graphic packages.

Finally, in the **Part III (Conclusions)** it is recommended that the results be presented in three levels: professional/scientific presentation; decision-making level; and information for the general public. The main outputs of an integrated/combined mapping and measurement programme are: maps and their interpretation; measurement results and their interpretation; conclusions on the basis of mapping and measurement results; and recommendations for the follow-up and management/protection measures.

The document also contains 2 annexes: Annex I - on the role of erosion mapping within the process of Integrated Coastal Area Management (ICAM); and Annex II - glossary of terms.

The presented erosion mapping and measurement framework has been applied and tested successfully under different sub-regional and national conditions. The prerequisites for its application can be met without special efforts in almost all the Mediterranean countries. However, in any particular case, need may arise for consultation and/or initial training, in which cases FAO/AGL, Ministry of Environment of Spain/DGCONA, or PAP/RAC may be contacted.

It is recommended that the two parts of the Guidelines be used together when formulating and implementing rainfall-induced erosion control programmes or projects.

Finally, there is a good probability that the basic concept of, and approach to the presented mapping and measurement methodology might be applied in other erosion prone regions, after a comparative analysis and adapting of the recommended procedures, as appropriate.

INTRODUCTION

1. BACKGROUND INFORMATION

The Regional Activity Centre of the Priority Actions Programme (PAP/RAC), operating within the Mediterranean Action Plan (MAP) - UNEP, has been implementing since 1984 the priority action entitled "Promotion of Soil Protection as the Essential Component of the Environmental Protection in Mediterranean Coastal Areas". The action has enjoyed the participation of almost all Mediterranean countries, FAO and the Arab Centre for the Studies of Arid Zones and Desert Lands (ACSAD), Damascus.

After an initial, fact-finding phase, a proposal of a **cooperative project on erosion mapping and measurement** in Mediterranean coastal areas was prepared jointly by PAP, FAO and ACSAD, and proposed for implementation at the 5th Ordinary Meeting of the Contracting Parties to the Barcelona Convention (Athens, 1987). The proposal was accepted and Spain offered to host the project. The Spanish authorities nominated their National Institute for the Conservation of the Nature - ICONA (now General Directorate for the Conservation of the Nature - DGCONA), Madrid, to act as the host institution of the project, while FAO agreed to contribute providing scientific and professional support.

Accordingly, the project was defined and divided in two parts, namely:

- a **pilot project on erosion mapping and measurement**, to be implemented, from 1991 to 1995, in three representative areas selected in Spain, Tunisia and Turkey; and
- a **larger project** in erosion mapping and measurement **to be implemented later on**, at a broader scale, with the participation of other interested Mediterranean countries, possibly as a UNDP project.

The proposal of the pilot project was discussed at an expert meeting held in Malaga in December 1989, and after the approval of the Contracting parties to the Barcelona Convention, the project was launched in 1991, being divided into a **component on mapping** and a **component on measurement of erosion processes**.

The **Mapping Component**, implemented by PAP, DGCONA and FAO, in collaboration with Spain, Tunisia and Turkey, was concluded towards the end of 1992 (the Vallcebre area in 1995-96). The results of the activity, as well as a common mapping methodology developed within it, were presented and discussed in a seminar held in Malaga in December 1992, attended by the participants of 10 Mediterranean countries and the EC. The seminar judged the developed methodology favorably and recommended that guidelines be prepared for its application. The terms of reference for the preparation of the mapping part of the Guidelines were formulated during two expert meetings (Rome, April 1993, and Almeria, June 1993). The authors prepared the draft version of their contribution by the end of 1993. The first revision of the draft version was made in Rome in March 1994, and the second one in January 1996.

The **Measurement Component,** implemented by PAP, DGCONA, and FAO was launched in 1993 and completed in early 1996. The results of the activity were analyzed and discussed in the expert meeting held in Barcelona in July 1996. The terms of reference for the preparation of Part II of the Guidelines were formulated during the expert meeting held in Madrid in November 1993. The first draft of the measurement part of the Guidelines was revised in the expert meeting organized in Barcelona in July 1996.

The final draft of both mapping and measurement components was presented, discussed and amended at a workshop organized in Barcelona on 13-16 October 1996. The amendments and proposals recommended by the workshop were taken into account as appropriate when editing the final text of Guidelines.

A special chapter on the role and place of erosion processes within the process of the Integrated Coastal Area Management (ICAM) in the region is contained as Annex I in the Guidelines.

Due to the complementarity of the mapping and measurement procedures, their joint use and application is recommended whenever possible and/or appropriate.

2. STATE OF RAINFALL INDUCED EROSION IN THE MEDITERRANEAN COASTAL AREAS

Mediterranean landscape is the result of long and intense interactions between human activities and natural environment. The soil is the essential component interfacing these relationships, and consequently has become deeply affected.

Soil erosion is severe in the Mediterranean basin and particularly intense in long sectors of its coastal areas. The extent of the phenomena is difficult to assess, nevertheless this point has been subject to attention, mainly at the national level, and some estimations are available.

In the Mediterranean countries of the European Union, 202,000 km^2 present high erosion risk (Giordano et al, 1992). Other data compiled by the United Nations indicate that as much as 200,000 km^2 of the Mediterranean region may be subject to desertification.

According to ICONA erosion maps, 57% (104,000 km^2) of the Mediterranean basins of Spain, are affected by erosion rates higher than 12 t/ha/yr, and 25,700 km^2 of them affected by very intense erosion rates of more than 50 t/ha/yr.

Research conducted in the Bleone watershed between Digne and Draix, Alpes Maritimes, France (CEMAGREF, 1988) have proved that two small catchments, one entirely covered by artificial plantations and other presenting bare land have a soil erosion rate of 0.01 t/ha/yr and 30 t/ha/yr respectively.

Turkey presents 22.3% of land severely eroded (Topraksu Koyisler, 1981).

In Tunisia the inter-annual and inter-seasonal irregularity of rainfall combined with the mountainous relief are the main physical factors leading to erosion. According to the erosion map of the northern part of the country, covering 120,000 km^2 of the 164,000 km^2 total area of Tunisia, 70,000 km^2 are directly threaten by erosion. (Abdesslam, 1994).

Gazzolo and Bassi (1966) indicated for Italy a mean specific erosion of 0.15 mm/yr, the highest being that of the Marecchia and Savio basins (both in Emilia-Romagna) with an annual soil loss of 1.4 mm (approx. 23 t/ha/yr). The explanation to this situation can be found in the particularly erodible soil and in the extremely intensive cultivation.

The Albanian Drin river has one of the highest suspended sedimentary load in the Mediterranean basin: 1,082 t/km^2/yr.

In Syria, Lebanon and Israel rainfall and wind induced erosion have a cumulative effect. Rainfall induced soil erosion rarely exceeds 50 t/ha/year (FAO/UNEP/UNESCO, 1980).

In Egypt there is no or negligible rain-induced soil erosion, but in several desert areas (erg) and in a narrow strip bordering the Nile delta and the western Egyptian coast wind-induced soil erosion may mobilize more than 200 t/ha/yr. Libya has moderate rain-induced soil erosion on the mountain range bordering the sea (Jebel Akdhar and Jebel Nefhusa), while in other parts there is extensive wind erosion.

From siltation surveys completed in six reservoirs located in several watersheds in Morocco arose that soil erosion ranges from 2 to 59 t/ha/yr.

The main physical factors influencing soil erosion processes in the Mediterranean region are:

- very high climatic variability characterized by frequent periods of drought and periods of heavy rainfall;
- presence of high erodible soils due to their weak structure, shallowness and lack of organic matter
- uneven relief with steep slopes and very diversified landscapes.

The main socio-economic factors influencing soil erosion in the Mediterranean region are:

- crisis conditions in traditional agriculture with associated land abandonment and deterioration of soil and water conservation structures;
- extensive forest and natural vegetation losses due to frequent wildfires;
- overgrazing of rangeland which has particularly strong environmental impact in semi-arid conditions;
- over-exploitation of agricultural land inducing soil erosion.

The effects of soil erosion are of environmental and economic importance.

On-site damages are loss of soil productivity and reduced agricultural yields.

Off-site effects are far reaching: increasing rates of siltation in streams and reservoirs affecting water quality and the drainage capacity of rivers.

Both on-site and off-site effects have a negative relevant influence on the water cycle, diminishing the natural capacity of the land for river regulation, in a region where water is a critical factor, which limits socio-economic development.

When addressing causes and consequences of soil erosion it is important to stress the great degree of integration and inter-relationship between the physical phenomena and the socio-economic context.

Most of erosion control plans have focused more on the symptoms than on the real causes of the phenomena. They have tried to tackle overcultivation, overgrazing, deforestation, etc. directly, without addressing the underlying social and economic pressures that have produced them. (Lean, 1995).

It is essential to understand the causes which trigger the human behavior in respect to soil erosion. The United Nations Convention to Combat Desertification, adopted in 1994, focuses on this integrated approach pointing out that affected countries have to "*address the underlying causes of desertification, and pay special attention to the socio-economic factors contributing to desertification processes*". Soil erosion is the leading direct mechanism of desertification world-wide.

The socio-economic context of soil erosion presents some differences between northern and the southern Mediterranean.

In the Southern Mediterranean, the erosion phenomena are mainly linked to the demographic increase. Since 1950 population has triplicate, while in the Northern Mediterranean has grown barely by 30%. As the irrigated area remains unchanged, an extraordinary increase of the agricultural pressure over the marginal lands have been necessary to keep the population. The overcultivation and overgrazing of uncertain yield appears and the soil erosion spreads. The forest area retreats about 1 to 2% yearly and the steppe and natural pasture are destroyed at a pace of 1% every year.

In the Northern Mediterranean the technical, economical and social changes of the rural life since 1950, led to the litoralization of the economy, characterised among others by the demographic vacuum in the less productive inner zones and an extreme concentration of the population in the littoral areas. The fast expansion of the abandoned marginal areas, prone to forest and wild fires, led to the deterioration and subsequent erosion processes. (Puigdefábregas, 1994).

All these processes show once more the critical relationship of the coastal areas with the watersheds that dominate them. The success of the coastal areas management requires the integral view of the whole watershed, which is the spatial scope where the water, ecological and geological cycles take place. Any disbalance in the upper part of the watershed could be felt in the lower coastal area.

In this inter-dependence the erosion phenomena can be taken as an example. The existence of sustainable ecosystems and agriculture in the upper parts, free of erosion phenomena, is critical for the regulation and quality of the vital water supply and the protection against the floods, which would put at risk most of the coastal areas. Furthermore, the socio-economical imbalance in the upper parts affect the equilibrium of the coastal areas and vice versa. The mentioned litoralization of the economy can be taken as an example.

It is remarkable that in all these processes erosion phenomena are present as a mechanism but also as an indicator of the sustainability and sound socio-economic integration of the coastal and upper areas of the Mediterranean watersheds.

The direct measures to mitigate and prevent erosion are well known. Some of them have been extensively applied in the Mediterranean basin.

The planning and design of erosion mitigation actions relies in the concept of Watershed Restoration and Management Project (WRM), which represents an integrated analysis of the land resources of the watershed and its degree of degradation, as a basis to formulate a proposal of sustainable land-use in terms of soil and water resources protection. (Rojo Serrano, 1996).

The land-use proposal must satisfy the socio-economic demands of the inhabitants, inside and outside the basin. The implementation of the WRM implies a series of activities to restore the eroded land and to prevent further development of soil erosion. The main actions considered are: Reforestation with Mediterranean species; Silvicultural treatments to improve and promote natural vegetation cover; forest management to consolidate and improve the ecological quality of existing forest stands; grazing management to achieve sustainability of pasture exploitation; agricultural soils conservation practices specifically designed to prevent soil erosion; and torrential watercourses stabilization structures, mainly check-dams to stabilize the deepening of gullies and scouring of "ramblas" which may lead to generalized channel erosion.

The WRM is not only a planning instrument of technical measures but also a tool to integrate the erosion control measures in the socio-economic context. The public information of the project and the official promotion of the prescript measures are among the mechanisms to reach such integration.

Experiences in erosion mapping and measurement provide the critical basic knowledge to assess the phenomena and formulate the mitigation actions required. The complex nature of the erosion phenomena with multiple physical factors implied, as well as the complexity of its off-site projection, calls for a sound scientific basis, which can be only established with an adequate field experimental programme.

The adequate address of the soil erosion problems as well as the correct formulation of mitigation and prevention plans requires the understanding of the complexity of the phenomena and their implications. It is essential to avoid simplifications which could lead to fictitious solutions, sometimes with undesirable collateral effects. In such a context the field measurement presents its real value as a tool to guide the management actions.

3. LINKS AMONG MAPPING/MEASUREMENT OF EROSION PROCESSES AND INTEGRATED MANAGEMENT OF COASTAL AREAS

Erosion is an essential factor to be considered in any territorial planning. This assert relies in the fact that the degree of erosion is a primary indicator of the sustainability of the land use scheme of a territory.

Erosion mapping is the essential tool for the knowledge of the distribution and geographic extent of the phenomena as well as for its qualitative characterization. The Common Consolidated Methodology of Mapping of Rainfall Erosion in the Mediterranean Coastal Areas, established as the first component of this co-operative project provides both predictive and descriptive mapping of the erosion phenomena.

Through erosion mapping, it is possible to incorporate the erosion phenomena as a factor in the process of land-use planning and management, and particularly in the process of Integrated Coastal Areas Management (ICAM).

The full capacity to integrate both methodologies, erosion mapping and ICAM, into geographical information systems (GIS), facilitates the joint use of both elements as a improved tool to guide decision making in the land-use planning and management of the Mediterranean coastal areas.

The erosion map provides a synthetic, systematic information about the nature, intensity and distribution of the relevant phenomena. On this basis is possible to identify the most severely affected areas and the dominant types of erosion. On a more detailed basis, the measurement of the erosion phenomena in selected environments provides accurate qualitative and quantitative data necessary as detailed inputs to ICAM, as well as the reliable basis for the planning and design of the prescribed erosion control activities.

The measurement area should be previously surveyed and mapped at both landscape and more specific, land unit levels, where identified erosion processes can be considered as representative.

Measurement operations and experiments are meant to complement or compensate for the lack of quantitative assessment within the systematic mapping procedure.

Erosion mapping identifies and describes dynamic processes in a qualitative way, including extreme situations such as overall irreversible degradation on one hand, and stable, non-affected areas on the other. Experimental measurement data would be of particular need and relevance to all intermediate and typical cases where land degradation, and specifically soil erosion, need to be quantified and assessed in terms of priority after having been identified and located by means of systematic mapping.

Measurement plots and experimental plots not related to any systematic mapping surveying have been considered of very reduced utility, especially if they have to be integrated in a management plan. The exercises related to experimental plots and watersheds mapping should be integrated in the general policy of erosion control. The results of the measurements should be used in the determination of the priorities of action and the design of technical solutions of a management plan. To this objective contributes essentially the formulation of a link between the different mapping units identified and the data from the corresponding experimental plots or watersheds. Therefore, a close association and interaction between erosion measurement and mapping have been recognized as one of key prerequisites of sound soil management and land-use planning.

Additionally, erosion measurement can be used for the systematic characterization of erosion landscapes extensively represented in the Mediterranean. This exercise includes the detailed description of the erosion-specific mechanisms and the quantitative data ranges associated to them. It has the potential to build a kind of systematic landscape inventory to be used as a primary reference for ICAM and general land planning purposes.

In summary, a close association and interaction between erosion measurement, erosion mapping and ICAM has been recognized as one of the key prerequisites of sound soil management in coastal areas.

4. PREREQUISITES AND INSTITUTIONAL ASPECTS

The application of a common, standardised mapping and measurement procedure by various countries offers great advantages related to the possibility of exchange of information, assistance, transfer of knowledge, implementation of comparative studies, joint research and/or technical programmes/projects. On the other hand, the application of the recommended procedures requires a certain number of prerequisites to be met. The most important of them are:

- **Political will:** The responsible political and executive authorities must develop and express a positive will to define and implement harmonized activities and adequate institutional instruments relative to soil protection and erosion control problems as an essential component of the national development/environment policy;
- **Institutional capacity:** The authorities, institutions and professionals involved (Government and administration at national and local levels; university departments and research institutions; institutes; soil management authorities) are supposed to possess an average level of appropriate organizational, scientific and/or professional capacity, and a certain previous experience in soil erosion related activities;
- **Capacity of integration:** Due to the fact that erosion phenomena are of a multidisciplinary and multisectorial nature, the will and ability to establish horizontal and vertical integration / coordination / cooperation, including the integration within a larger ICAM framework, is highly necessary;
- **Knowledge** of erosion related problems: a certain level of information and scientific knowledge of relevant and representative erosion phenomena; understanding of impacts of erosion processes on the national economy and environment; understanding of the benefits of application of a common consolidated methodology; finally, understanding of priorities.
- **Existence of a National Erosion Control Programme,** as part of the National Development Policy and Strategy;
- **Existence** of a specific, **area-related Erosion Control Programme**, as part of the National Programme.
- **Public awareness**, to be achieved through education, information, demonstration and sensitizing of the farmers at household and rural community levels.

The experience gained by PAP/RAC in the implementation of the programme indicates that the above prerequisites can be reasonably met in almost all of the Mediterranean countries. However, even if some of these prerequisites do not exist, or are not fully met, it is strongly recommended that training courses be organized in order to achieve the necessary level of capacity and experience. Furthermore, preparatory training, and on-the-job training in particular, are recommended when starting the application of the presented procedures.

PART I:
MAPPING OF RAINFALL-INDUCED EROSION PROCESSES

1. GENERAL CONTEXT

1.1 Hitherto Experience in Mapping of Rainfall-Induced Soil Erosion in the Region

In order to prepare a common methodology for rainfall induced soil erosion mapping in Mediterranean coastal areas, the state of the art on soil erosion mapping has been assessed. The aim was to investigate and analyze existing methodologies and/or mapping of soil erosion to find out common elements and correlations and to point out which methodologies and mapping are most suitable for a variety of scales and problems.

The investigation has been carried out analyzing information collected by FAO, A. Giordano and L. Rojo (1988) or directly supplied by national technical staff.

Twenty-nine different erosion maps were analyzed. They were grouped according to their approach and objectives. Two topics have received special attention: present rainfall induced erosion rates with seven mapping examples and soil erosion risks in seven cases.

The remaining 15 maps were dealing with other topics such as:

- soil erosion assessment using sedimentation data .... 2 maps
- rainfall and wind induced erosion data (qualitative assessment) .... 2 maps
- current state of soil erosion, landslides and mass movements ..... 6 maps
- wind erosion risk............................ 1 map
- desertification .... 1 map
- protection of natural resources and ecosystems.............................. 1 map
- use of remote sensing .... 2 maps

The following are some examples of quantitative mapping of rainfall-induced erosion:

- "Provisional map of the present degradation rate (t/ha/yr)" (FAO / UNEP / UNESCO, 1980), referring to the Middle East and North Africa (scale 1:5,000,000).
- "Mapa de estados erosivos (t/ha/yr)" (ICONA, 1988). The map scale is 1:400,000.

The two above-mentioned maps are based upon USLE but with considerable modifications, especially as far as the rainfall erosivity is concerned. This approach still needs practical experimentation.

Other maps dealing with the current rainfall induced erosion rate are those of ICONA (1982), Gazzolo and Bassi (1966), Gavrilovic (1962), Lazarevic (1985), Michaelides (1989) and Ciccacci et al. (1988).

As related to the qualitative approach of soil erosion risk, it is convenient to mention the map "Soil erosion risk and important land resources in the southern EC countries" (DG XI, EC, 1989 CORINE Programme). The aim of CORINE is to set up a working prototype information system (GIS) on the state of the environment and natural resources in the European communities. The project "Soil erosion risk" is only one, though important, part of the CORINE programme which covers issues such as biotopes, air quality, land cover, coastal erosion etc. The methodology involves separate assessment of two different, although related, indices of soil erosion risk i.e. the "potential soil erosion risk" and the "actual soil erosion risk".

A comparative analysis of erosion risk classes and those of important land resources provides accurate information on the priority area to be protected.

For a full description and critical analysis of the cartographic documents see Giordano e Marchisio (1992).

The difference between the two approaches (current rainfall induced erosion and erosion risk) is not so deep since both of them are using the USLE methodology with a certain number of modifications. A starting approach based on the risk concept that may be called "predictive" is important but it appears static. Combining the predictive method with a descriptive one in which emphasis is placed on the erosion processes, a sound cartographic base might be available with experimental field. Out of CORINE which is of very small scale, no medium to large-scale erosion mapping for both quantitative and qualitative assessments are available.

The overall analytical inventory of the state of the art of erosion mapping in Mediterranean coastal areas leads to two basic conclusions:

- the hitherto prepared maps provide data on either predictive or descriptive aspects of soil erosion processes;
- a number of different approaches, methods and scales have been used up to date, hindering any systematic correlation and integration.

Therefore the basic task of the PAP/ICONA/FAO project "Erosion mapping in Mediterranean coastal areas" was to overcome the above referred constraint i.e. to make available a new medium to large-scale consolidated and adequate mapping tool applicable in all Mediterranean countries.

1.2 Justification for a Common Consolidated Mediterranean Methodology

In the overall and very broad field of earth sciences, there has always been a basic and strong need for the graphic presentation of landscapes and geomorphic dynamics, that means systematic mapping to be used as both a descriptive and thematic surveying tool.

Mapping procedures have been progressively established and related to basic criteria, such as the reference theme, scale, accuracy, legend and symbols; main fields of application have been topography, geology, soil classification and more dynamic topics such as vegetation cover, land use, agronomic constraints and man-induced degradation.

Spatial reference frameworks were almost always the state or country boundaries since original and local mapping modalities were to some extent meant to secure and protect specific territories and to help preserving national identities.

As communications, interrelations and cooperation norms between countries improved, there was an increased need for more and more integrated and enlarged management strategies at sub-regional, regional or even continental levels. These opening processes implied common standardized and homogenized technical and scientific tools and languages amongst which surveying, mapping and classifications are to be considered as essential. This was particularly relevant for soil surveying and mapping when at least three different basic schools and approaches had produced important amounts of cartographic and statistic materials for which considerable funds and efforts had to be spent for their further correlation and more universal use.

In the specific field of soil erosion mapping most of the Mediterranean countries have elaborated a great amount of mapping systems and legends referring to a large variety of critieria and parametres which always lead to two main approaches: predictive erosion status or erosion processes description.

Up to date, only very small-scale erosion maps integrating both erosion potentials and active erosion processes are available, while there is an ever more urgent need for large-scale integrated erosion maps for regional and sub-regional planification purposes, as well as for the identification of priorities and of preventive (on the basis of potential erosion status) and curative (according to actual erosion problems) measures to be improved. Common action in these fields and at the scale of overall Mediterranean coastal areas are still strongly hindered by the lack of correlation and normalization of the extremely diversified erosion mapping concepts within rather reduced geographical areas.

The proposed common consolidated Mediterranean erosion mapping methodology has been elaborated to avoid this type of constraint and restrictions by providing common criteria leading to common scales of erosion intensity and priorities as identified through the final mapping data and diagnosis. Standard problem inventories and diagnosis should lead further on to common planning and management policies or strategies able to overcome national and cultural boundaries for the benefit of enlarged geographic units, such as the Mediterranean coastal areas.

2. COMMON CONSOLIDATED METHODOLOGY

2.1 General Description

The common consolidated methodological erosion mapping scheme is the result of two complementary approaches combining the advantages of a broad variety of surveying, processing and mapping techniques. In this exercise, key contributions were provided by DGCONA as the lead institution and FAO providing scientific and technical advise.

Two main basic approaches have been taken into account, namely:

- **Predictive** by identifying, assessing and integrating all basic parameters, such as physiography (slopes), lithology and/or soils, land, vegetation cover, in view of determining preliminary assumptions on erosion risks (erodibility - potential erosion);
- **Descriptive** when describing and qualitatively assessing current on-site and active erosion processes.

The consolidated scheme has been prepared so as to match with parallel measurement operations meant to evaluate actual soil loss by measuring discharges in experimental plots and/or sub-watersheds affected by specific and well representative erosion constraints.

The various operation sequences and steps related both to measurement and mapping are schematically shown in Fig. I-1.

The predictive approach provides considerable advantages in the initial surveying phase, such as speed, relatively low cost and less need for experienced staff.

Descriptive surveying is to be considered as complementary to predictive surveying, since it provides basic "field truth" which is either to consolidate or partly invalidate both active and potential erosion diagnoses.

The final consolidated approach requires various methodological steps within a general sequence where the main phases consist of basic **erosion status** mapping, processing and adjustment of intermediate basic erosion status map, and **site descriptive erosion process** mapping.

Basic reference grids and maps should be of a medium to large scale, thus providing clear contour-figured topographic information.

As far as basic erosion status mapping is concerned, the following specific factors and parameters are considered:

- **Topographic slope units** and classes expressed in degrees or percent.
- **Lithology/parent material/soils,** where emphasis is put on mechanical resistance and capacity of the various "lithofacies", rocks or loose sediments rather than of their petrographic or mineralogical peculiarities; the legend ranges from non-weathered hard and compact rocks to medium or strongly weathered material, and loose, non cohesive sediments.
- **Present land use and vegetation cover** are mainly identified by photo-interpretation; their overlapping and correlation determine the level of soil protection.
- **Erodibility levels** are determined by overlaying slope values and lithology maps (see 3.2 Predictive Approach, Step III).

The final **erosion status** map is the result of overlaying and correlating the maps of level of soil protection and erodibility levels.

The site **descriptive erosion process,** surveying and mapping, is performed through combined photo-interpretation and field control using the readjusted intermediate scale erosion status map as the new cartographic reference canvas, which means that active and specific erosion-affected areas and units are to be delineated by sub-boundaries inside the erosion status unit grid and boundaries.

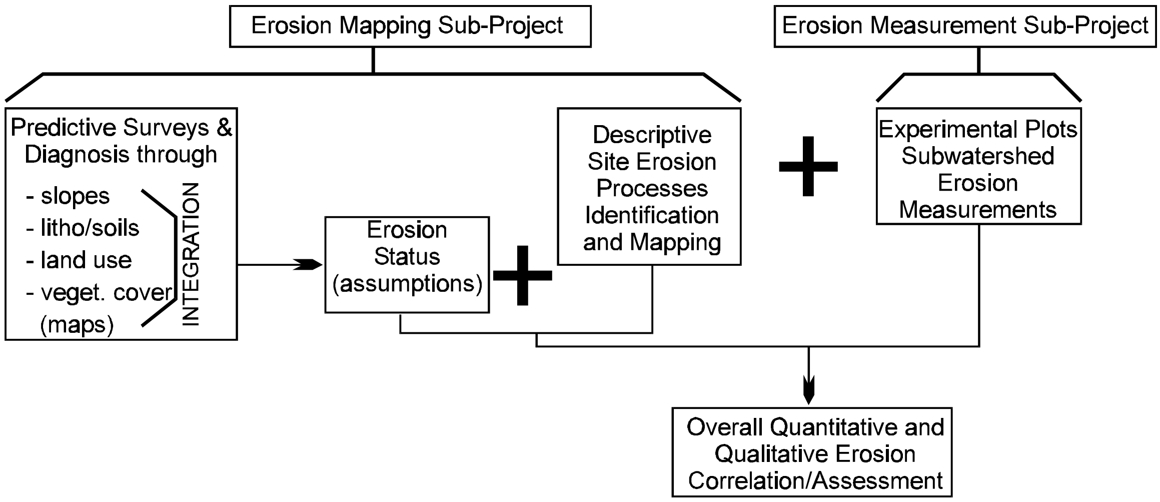


Figure I-1. General sequence of erosion mapping and measurement methodologies

The systematic mapping of qualitative and dynamic erosion features identifies two broad categories of geographic environments: morphologically **stable, non-erosion-affected areas**; and **unstable, erosion-affected areas**.

As related to the first category, a qualitative assessment is provided for **erosion risk** or **potential erosion,** identifying at field level, the various parameters considered for the basic predictive erosion status map and assessing their comparative de-stabilizing force. The latter should lead, in each specific case, to the identification of the main or most probable causative factor of medium- to high-erosion risks by means of codes and symbols given in the more detailed legend description (Chapter 2.2).

As far as erosion-affected areas are concerned, the descriptive and qualitative erosion mapping identifies the nature of specific erosion processes, their comparative **importance** expressed in terms of extent, size, depth or volume, and their **expansion rate** or **trend** based on field observations indicating either a recession or an increase of erosion activity.

2.2 Legend

The consolidated erosion map legend has been kept open and flexible enough to be adequate and adaptable to a reasonable variety of specific Mediterranean geographical backgrounds which are all related to coastal zone environments, but with numerous local micro-climatic, lithologic and land use variables. Special emphasis has been given to the following aspects:

- agro-ecological or bio-geographical zoning for different mapping scales and surveying conditions;
- soil surface state assessment (surface crusting and sealing) and the consequences on run-off and infiltration water dynamics[1];
- mechanical and/or chemical changes occurred in soils as a result of specific cropping or land use techniques (compacting)[1];
- specific identification and assessment of erosion-affected areas due to infrastructure depletion (roads, old terraces, check dams, etc.).

Overall geographical environments can be subdivided in two broad categories:

- **Stable**, non-erosion-affected areas, and
- **Unstable**, erosion-affected areas.

The erosion map legend as described in Box 1 has been prepared according to the referred landscape classification as a basic reference framework and a guide to both a predictive and descriptive diagnosis.

[1] Features to be considered as part of the lithology/parent material parameters to be integrated in the phase of erosion status mapping

BOX 1:

Legend

A. PREDICTIVE MAPPING: INFERRED GLOBAL EROSION HAZARDS

Symbols

(0)	**none** (Equivalent to **stable non-used wasteland** in **descriptive mapping: 010**)
(1)	**very slight**
(2)	**slight**
(3)	**moderate**
(4)	**severe**
(5)	**very severe**

B. SITE-DESCRIPTIVE MAPPING: GRADE OF STABILITY/EROSION PROCESSES[1]

I. **Stable,** non-erosion-affected areas (*)

00	**stable, non-used wasteland** (rock outcrops, cliffs, stony or sandy areas)
01	**stable, unmanaged areas with potential for forestry use only**
02	**stable, unmanaged areas with agricultural potential** (crops and pasture)
03	**stable, managed areas with forestry use only**
04	**stable, managed areas with agricultural use** (crops and pasture)

- **Rehabilitated areas by means of:**

05	**natural or artificial re-vegetation**
06	**physical infrastructures** (terraces, check dams, etc.)

*__Grade of instability risk__

Assessment of **instability risk** for all **stable** environments (00 to 04) and of risk for **rehabilitated** environments , i.e. 05+06 (i.e. a risk in the first years of rehabilitation;) to be expressed by a complementary digit (0 to 3) to the original **stable units'** code:

0: No risk (= highest grade of **stability**)

1: Low to moderate

2: High

3: Areas in hazardous/precarious/critical state (Stability threshold = highest grade of **instability risk**)

Example : 03 = **stable** managed areas

: 032 = **stable** managed areas with a high **erosion risk**

*__Identification of main causative agents__

Instability risk assessment may be reinforced by the identification of its most probable/prevailing **causative agents** inherent in the **landscapes'** main basic components, i.e.:

t: Topography
g: Geology
v: Vegetation
h: Human activities
a: Animal activities (trampling, terracing, etc.)

Extra codes might be freely added according to local specific contexts and situations.

Example: 023 **g** = stable managed areas with erosion risk mainly due to geologic factors.

II. U**nstable** areas (**)

- ***Splash erosion***

A1	**localized** (<30% of the area is affected)
A2	**dominant** (30-60%)
A3	**generalized** (>60%)

- ***Sheet erosion***

L1	**localized**
L2	**dominant**
L3	**generalized with soil profile removal**
Lx	**= unreclaimable areas due to total soil removal**

- ***Rill erosion***

D1	**localized**
D2	**dominant**
D3	**generalized**

- ***Gully erosion***

C1	**individual gullies**
C2	**localized gully networks**
C3	**dominant**
C4	**generalized**
Cx	**= unreclaimable areas due to generalized band lands**

- ***Wind erosion***

E1	**localized loss of topsoil/overblowing/deflection**
E2	**dominant**
E3	**generalized**

[1] Refer to the glossary for the definition of terms

Ex **= unreclaimable areas due to total sand or sediment burying or topsoil removal**

- ***Mass earth movements***

M1 **local gravitational soil creep/solifluction**

M2 **localized land slides/mudflows**

M3 **dominant**

M4 **generalized**

MX **= unreclaimable areas due to total slope slides**

Symbols

- ***Water or sediment excess***

W1 **areas periodically flooded and/or sediment buried**

W2 a**reas permanently flooded and/or sediment buried/waterlogged areas**

- ***Degradation induced by land management***

S1 **soil compacting**

K1 **soil crusting**

Z1 **cattle trampling/terraceting**

H1 **salinisation**

- ***Associated processes***

See "Note" in para (**)

Multiple processes

P1 P2 P3 etc.(for description of different closely interacting erosion processes)

****Erosion expansion trend (rate)**

Assessment of erosion rate/trend for all **unstable** erosion-affected areas to be expressed by a complementary digit (0 to 3) to the original **unstable units'** code:

0: Trend to **stabilization, recession** or limitation of spatial **expansion**

1: Trend to local **expansion** or **intensification**

2: Trend to widespread **expansion** or **intensification**

3: Trend to increase **generalized degradation** towards an **irreversible state**

Example:

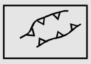
L2 = dominant sheet erosion

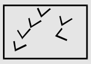
L23 = dominant sheet erosion with a trend towards generalization and an irreversible state (Lx type units)

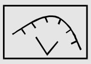
Note: All multiple or mixed but clearly identifiable erosion processes can be mapped by associating or combining the corresponding codes (the sequence of the codes should be established according to the relative importance of the processes: first code = the most important process):

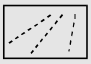
Example: L_{11}/C_{12} = Localized sheet erosion combined with dominant gully networks with a trend to widespread expansion or intensification.

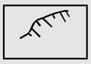
- ***Point/line erosion data (Individual erosion processes)***

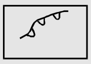
 **rocky canyon**

 **individual gully and/or gully head**

 **individual landslide/mudflow**

 **gravitational stone fan**

 **waterways bank erosion**

 **coastal erosion line**

3. PROCEDURES

3.1 General Methodological Scheme

As already referred to in the general description of the methodology (Ch.2.1), the basic procedure scheme consists of 3 clearly defined phases:

- **Predictive** phase which leads to the mapping of **erosion status** homogeneous units providing the basic cartographic canvas as far as general erosion potential and trends are concerned;
- **Descriptive** phase which identifies and assesses actual on-site erosion processes as well as the different grades of erosion proneness and evolution trends;
- **Integration** phase the main output of which is the final consolidated rainfall-induced erosion map as a result of overlapping and integrating predictive and descriptive qualitative data.

The predictive phase mainly consists of desk and office data processing by means of 7 different steps:

- Steps 1 and 2: Preparation of slope classes and lithofacies maps;
- Step 3: Erodibility map by overlaying slopes and lithofacies;
- Steps 4 and 5: Preparation of land-use and vegetation cover maps;
- Step 6: Soil protection map by overlaying land use and vegetation cover maps;
- Step 7: Erosion status map by overlapping erodibility and soil protection maps.

The descriptive phase is basically performed in the field by direct observation and control, using the predictive erosion status map as both a cartographic and thematic reference canvas. Field observation should be supported by photo-interpretation, particularly during the preliminary steps which consist of the identification of the stability grade, dominant erosion processes and evolution trends within the various erosion status units.

The integration phase produces the final consolidated erosion map by consolidating all predictive and descriptive data.

The comprehensive graph shown in Fig. I-2 summarizes the overall methodological sequence and clearly identifies the various mapping phases including the final integration leading to the consolidated erosion map.

For all overlaying and integration procedures envisaged, the use of GIS as an efficient tool, highly appropriate for the decision-making process, is recommended.

It is emphasized that the purpose of the map and its future target users have to be clearly defined before starting with the mapping exercise. Erosion mapping cannot be understood as an end itself, but must always aim for indicating needs for and possibilities of future soil conservation activities by the means of planning both short term curative programs and longer term preventive policies. The respective planning steps will include the identification of extreme situations as well as future priorities of action and the respective curative / preventive measures.

3.2 First Phase: Predictive Approach

<u>Step 1: Preparation of the slope map from the topographic map</u>

The procedure starts with the delimitation of all identifiable thalwegs on the basic contour topographic map, be those sporadic or permanent water courses. This approximation enables us to delimit all the boundary lines of the slopes, as the thalweg coincides with the bottom of one slope and the beginning of the other (Fig. I-2). Most of the thalwegs figure as watercourses in the topographical map; therefore, only the unmarked thalwegs, which usually coincide with small rivers or gullies, should be additionally drawn.

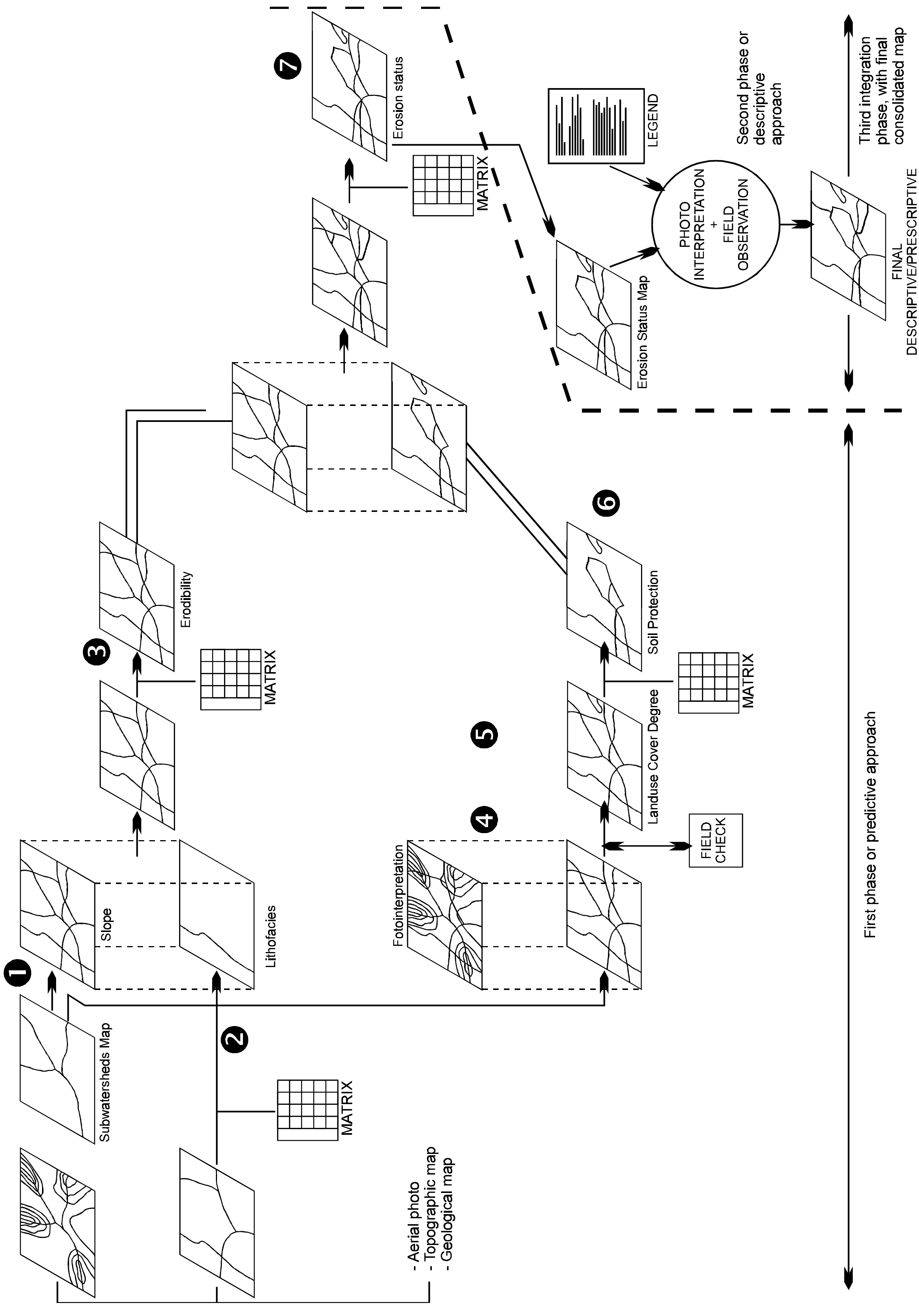


Figure I-2. Main operational sequence of erosion mapping procedures

Box 2

Mapping scale

Erosion mapping, whether predictive, descriptive or integrated, should be closely adapted to the selected mapping scale, which means that the expected cartographic diagnosis should not be overestimated as related to the actual accuracy capacity of the map scale and legend. The basic mapping resolution of the map is determined by the minimum linear (1 cm) or area (1 sq. cm) dimensional expression of erosion processes on the map whatever its scale (e.g. 100 m / 1 ha at 1:100,000; 50 m / 0.25 ha at 1:50,000; etc.)

Most suitable map scales can be classified as follows:

- At farm, household or plot level, very large scales, from 1:5,000 to 1:10,000, mainly for detailed planning or land-management surveys;
- At small sub-catchment and catchment level, large to medium scales, from 1:25,000 to 1:50,000;
- At regional level, the usual reconnaissance scale of 1:150,000 or 1:250,000;
- At medium country level, small scales from 1:600,000 to 1:1,000,000.

For the current erosion mapping programme, a medium working scale of 1:50,000 has been agreed upon, with further possibility to reduce the original detailed erosion data to smaller scales meant to be used in priority identification and soil and water conservation planning maps (1:100,000 to 1:200,000).

Once the thalwegs figure in the map, watersheds divides have to be identified and drawn (see Fig. I-3). The purpose is to identify mountain sides regardless of any minor physiographic change within the slope.

At that stage the map of sub-watershed has been produced. This map will be used as the basic canvas and reference map for the land-use photo-interpretation. All the maps and copies prepared should be drawn on transparent indeformable polyester sheets.

Once the thalwegs and divides have been drawn, it is necessary to identify the large continuous slopes which reflect main topographic features (see Fig. I-4).

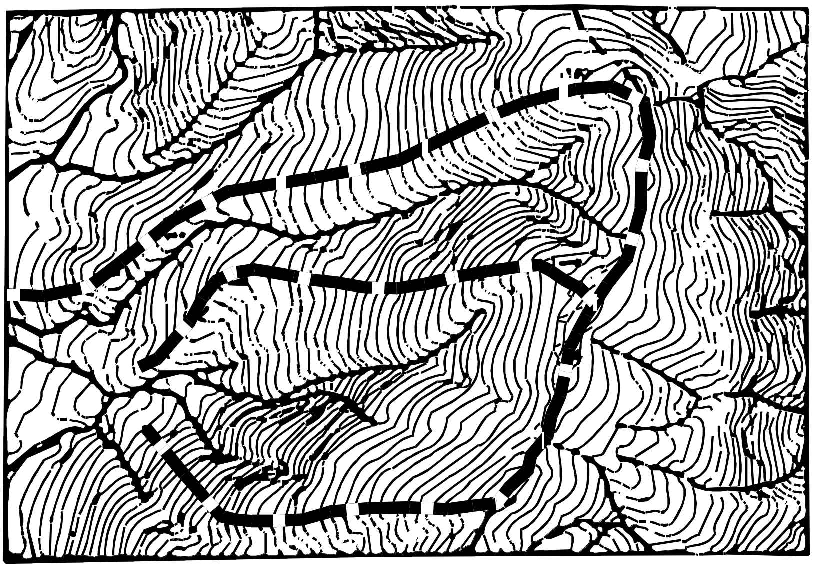


Figure I-3. Identification of divide lines

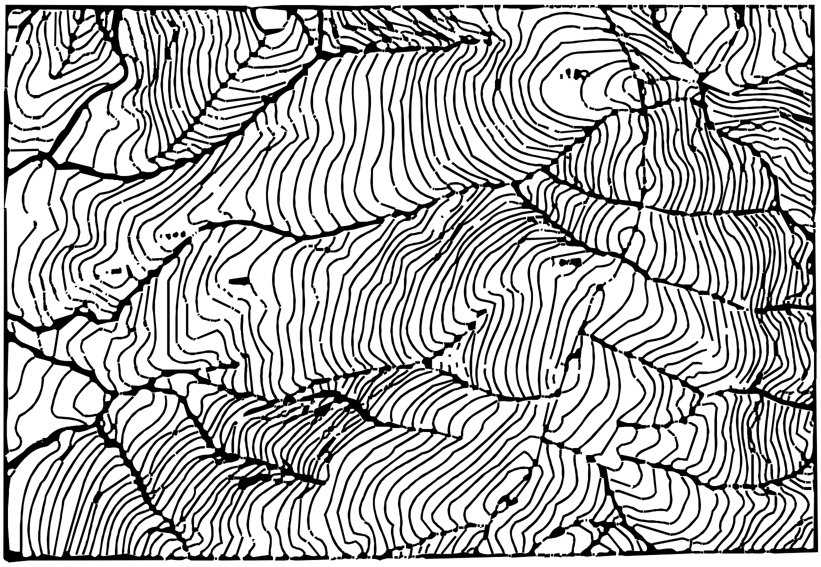


Figure I-4. Preliminary mapping of large sloping units

After having located and mapped the large slope polygons, topographic breaks and slope changes inside the polygons are identified and mapped. The result of that operation is the topographic mosaic map which shows homogeneous topographic units. (see Fig. I-5).

Once the topographic mosaic map is finished, slope values for each of the identified units are to be determined. Therefore, the number of countour lines contained within the reference mapping section measured in milimeters have to be counted and then related to in the Table 1, where the slope inclinations are expressed in percentages for each of the referred areas (see Table I-1 and applied examples in Fig. I-6 and I-7).

As additional information, the sloping direction of each unit may be represented by a short line starting from the divide line downward. For the interpretation of the slope map the slope orientation (North facing, South facing, etc.) could be taken into consideration.

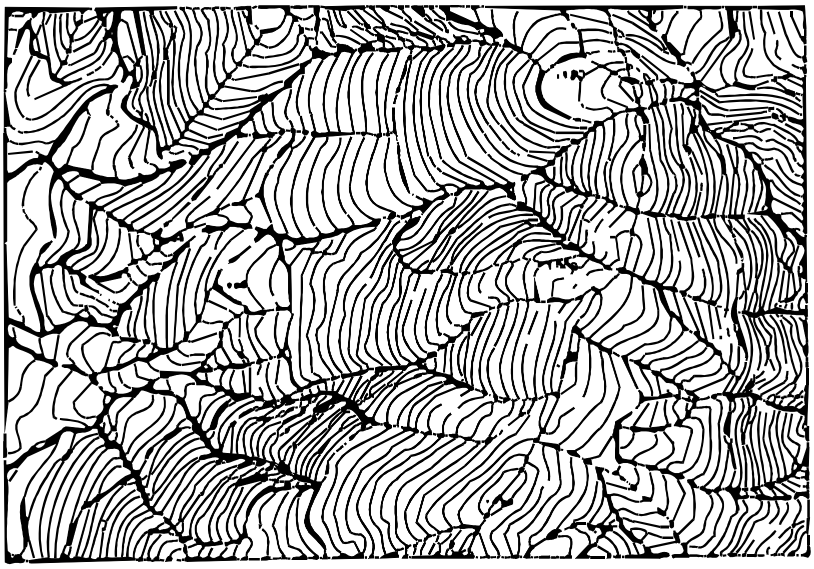


Figure I-5. Topographic mosaic map

Number of intervals	Length of sloping sections in mm													
	1	2	3	4	5	6	7	8	9	10	15	20	30	40
1	40	20	13.0	10	8	6.0	5.7	5	4.4	4	2.6	2	1.3	1
2	80	40	26.6	20	16	13.3	11.4	10	8.8	8	5.3	4	2.6	2
3	-	60	40.0	30	24	20.0	17.1	15	13.2	12	8.0	6	3.9	3
4	-	80	53.3	40	32	26.6	22.5	20	17.6	16	10.6	8	5.2	4
5	-	100	66.6	50	40	33.3	28.5	25	22.0	20	13.3	10	6.5	5
6	-	-	80.0	60	48	40.0	34.2	30	26.4	24	16.0	12	7.8	6
7	-	-	93.3	70	56	46.6	39.9	35	30.8	28	18.6	14	9.1	7
8	-	-	-	80	64	53.3	45.6	40	35.2	32	21.3	16	10.4	8
9	-	-	-	90	72	60.0	51.3	45	39.6	36	24.0	18	11.7	9
10	-	-	-	100	80	66.6	57.0	50	44.0	40	26.6	20	13.0	10
11	-	-	-	-	88	73.3	62.7	55	48.4	44	29.3	22	14.3	11
12	-	-	-	-	96	80.0	68.4	60	52.8	48	32.0	24	15.6	12
13	-	-	-	-	104	86.6	74.1	65	57.2	52	34.6	26	16.9	13
14	-	-	-	-	-	93.3	79.8	70	61.1	56	37.3	28	18.2	14
15	-	-	-	-	-	100.0	85.5	75	66.0	60	40.0	30	19.5	15
16	-	-	-	-	-	-	91.2	80	70.4	64	42.6	32	20.8	16
17	-	-	-	-	-	-	96.9	85	74.8	68	45.3	34	22.1	17
18	-	-	-	-	-	-	102.6	90	79.2	72	48.0	36	23.4	18
19	-	-	-	-	-	-	-	95	83.6	76	50.6	38	24.7	19
20	-	-	-	-	-	-	-	100	88.0	80	53.3	40	26.0	20
	Slope inclination in percentage (%)													

Table I-1. Slope values

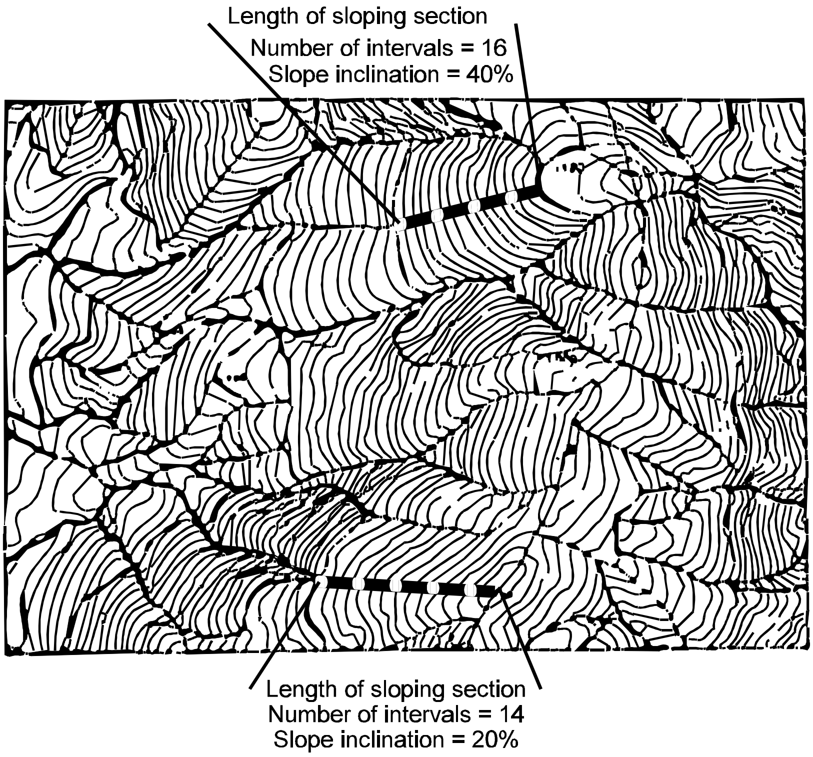


Figure I-6. Length and value of sloping sections

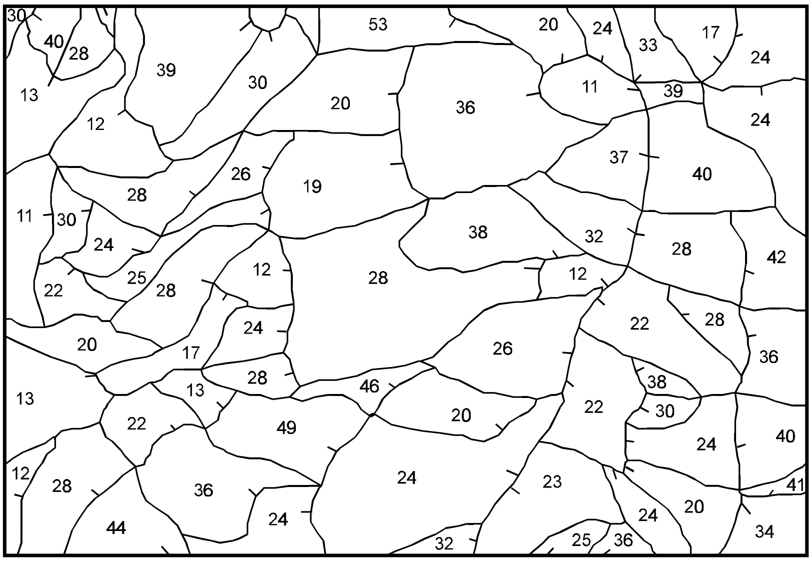


Figure I-7. Map of slopes

Slope classes are shown in Table I-2.

Classes	Type of slope
1.	Flat to gentle slopes (0-3%)
2.	Moderate (3%-12%)
3.	Steep (12%-20%)
4.	Very steep (20%-35%)
5.	Extreme (>35%)

Table I-2. Slope classes

Step 2: Elaboration of the lithofacies map

The procedure is based on the geological, lithological and pedological maps and data. The map shows the kind of rock, parent material or surface sediment/soil, with emphasis on their cohesiveness in order to present their inherent resistance to both mechanical and chemical erosion.

Complementary features specifically related to soil, such as soil structure, impermeability, clay content, water storage capacity, should be taken into account.

The Lithofacies map legend considers the classes as presented in Table I-3.

The areas with abundant (40-80%) to dominant (>80%) rock outcrops and/or surface stoniness should be identified and outlined in all maps (not only in the lithofacies map), and classified as non-productive areas (class /a/ of Table I-3). This same classification is to be applied to areas such as water bodies, quarries, beaches, urban or industrial sectors, etc.

Lithofacies classes	Type of material
(a)	Non-weathered compact rock, strongly cemented conglomerates or soils, crusts, hard pans outcrops (massive limestone, highly stony soils, igneous or eruptive rocks, locally crusted soils).
(b)	Fractured and/or medium weathered cohesive rocks or soils.
(c)	Slightly to medium compacted sedimentary rocks (slates, schists, compacted marls, etc.) and/or soils.
(d)	Soft/low-resistant or strongly/deeply weathered rocks (marls, gypsum, clayey slates, etc.) and/or soils.
(e)	Loose, non cohesive sediments/soils and detritic materials.

Table I-3. Lithofacies classes

Step 3: Preparation of erodibility map

Erodibility map is the result of overlaying the slope map and the lithofacies map (see Fig. I-8).

The polygons resulting from the overlaying of the two reference maps are classified according to the following matrix shown in Table I-4.

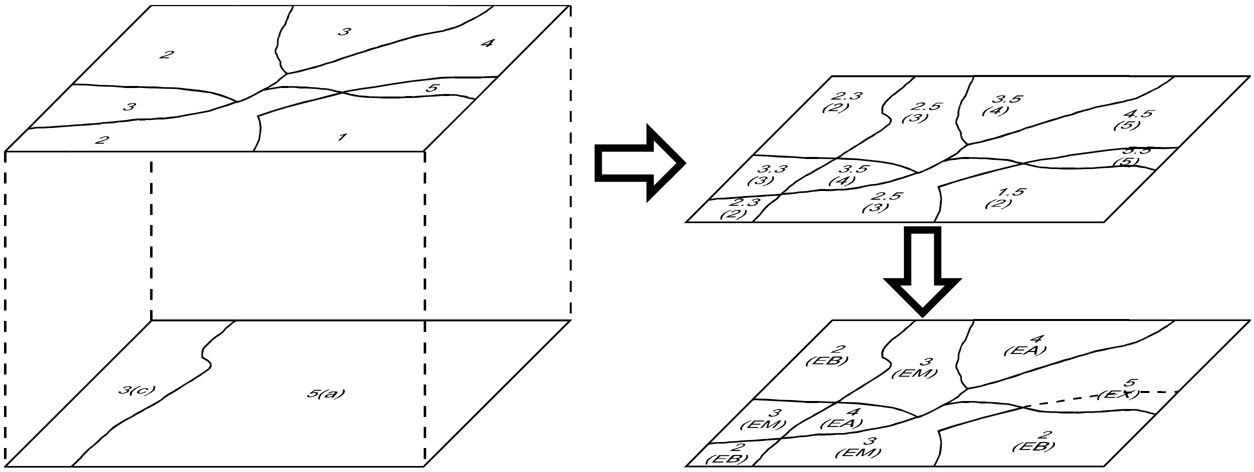


Figure I-8. Erodibility map processing

Slope class	Lithofacies class				
	1(a)	**2(b)**	**3(c)**	**4(d)**	**5(e)**
1.	1(EN)	1(EN)	1(EN)	1(EN)	2(EB)
2.	1(EN)	1(EN)	2(EB)	3(EM)	3(EM)
3.	2(EB)	2(EB)	3(EM)	4(EA)	4(EA)
4.	3(EM)	3(EM)	4(EA)	5(EX)	5(EX)
5.	4(EA)	4(EA)	5(EX)	5(EX)	5(EX)

Table I-4. Matrix: Slope vs. lithofacies

Classes	Potential erosion
1.	Low (EN)
2.	Moderate (EB)
3.	Medium (EM)
4.	High (EA)
5.	Extreme (EX)

Table I-5: Levels of erodibility

Steps 4 and 5: Preparation of land-use and vegetation cover map

Both actual land use and vegetation cover are first identified by photo-interpretation, and then transferred to the sub-watershed map. Land-use and vegetation cover classes are given in Tables I-6 and I-7.

It should be noted that the scale of the aerial photo does not necessarily coincide with the selected scale for mapping. The mapping scale is selected with regard to the criteria shown in Box 2. Therefore, an adjustment operation has to be done when transferring the photo-interpretation patterns to the basic topographic map.

BOX 3

Developed methodology

As an overall recommendation, the methodological framework should not be considered as a rigid scheme, but rather as a set of guidelines in which the cartographic concepts, units and symbols of which should be easily adapted to specific geographical country or regional features.

In the predictive phase the content (qualifications) of the double entry tables (matrix) can be adapted to the specific conditions of each country or region. In particular the different vegetation cover classes and their qualifications in the tables should be defined according to the specific local conditions.

> In the descriptive phase, the adaptation could be possible by opening new categories of processes or characteristics in addition to those proposed in the original legend under the paragraph "Multiple processes" P_1, P_2, P_3... for newly identified erosion forms or trends.

Classes	Land use
1.	Dry farming (herbaceous)
2.	Ligneous crops (olive, almonds, fruit trees, vineyards)
3.	Irrigation
4.	Forest
5.	Shrub
6.	Range, sparse shrubs

Table I-6. Land use classes

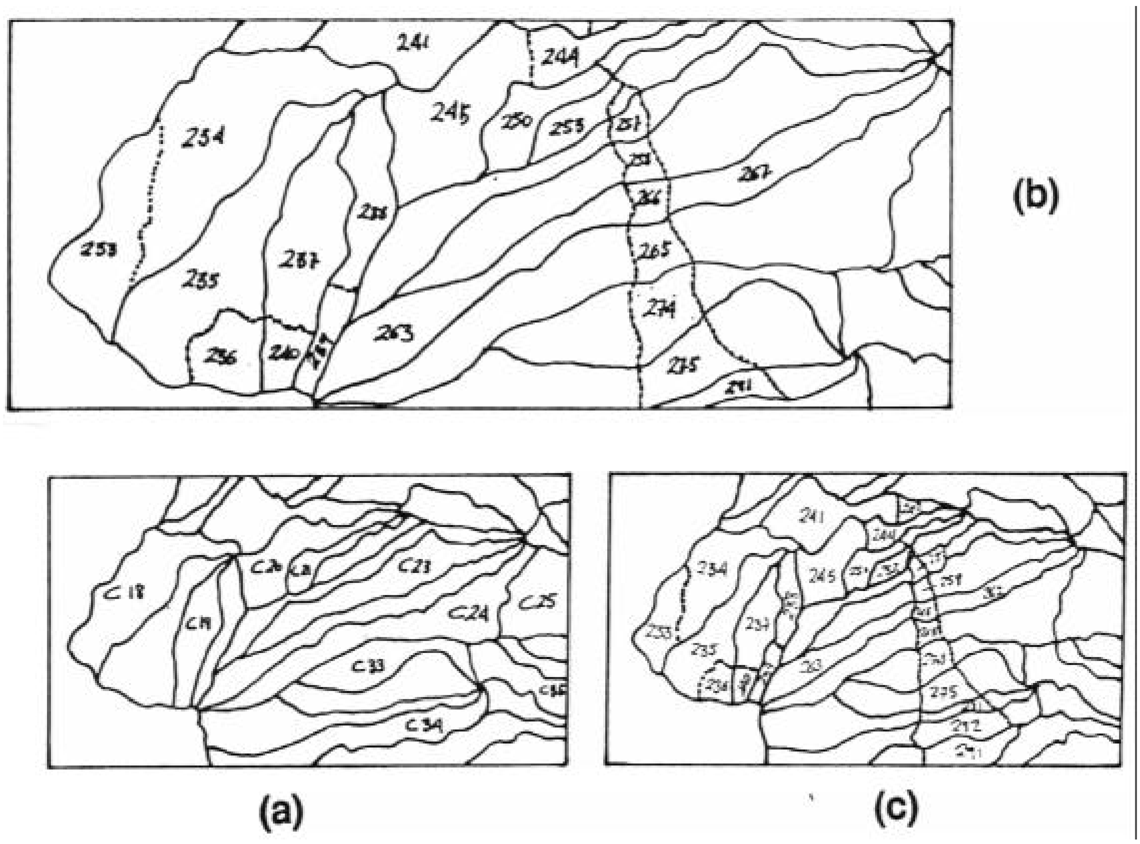
Classes	Vegetation cover
1.	Less than 25%
2.	25% - 50%
3.	50% - 75%
4.	More than 75%

Table I-7. Vegetation cover classes

The sequence of photo-interpretation and mapping procedure for land use and vegetation cover identification is shown in Fig. I-9.

If possible, recent aerial photographs from different periods of the year should be taken into account in order to consider changes/variations in the vegetation cover/land use throughout the year.

Photo-interpretation has to be checked by field visits and corrected if necessary. The slope map provides a useful reference for polygon identification in the field.



(a) Sub-watershed basic reference map (1:50,000).
(b) Land-use and vegetation cover photo-interpretation and resulting polygons (≅ 1:30,000).
(c) Final land-use/vegetation cover mapped on the sub-watershed reference map (1:50,000).

Figure I-9. Sequence of mapping procedure and actual land-use and vegetation cover mapping procedure

Step 6: Preparation of soil protection map

The map of soil protection levels is obtained by applying the matrix presented in Table I-8.

Applying the matrix and legend given in Table I-8, the boundaries between polygons with equal levels of soil protection are deleted (see Fig. I-10).

Land use	Vegetation cover			
	1	2	3	4
1	5(MB)	5(MB)	4(B)	4(B)
2	5(MB)	5(MB)	4(B)	3(M)
3	3(M)	2(A)	1(MA)	1(MA)
4	4(B)	3(M)	2(A)	1(MA)
5	5(MB)	4(B)	3(M)	2(A)
6	5(MB)	4(B)	3(M)	2(A)

Levels of soil protection (Legend):
1. Very high (MA)
2. High (A)
3. Medium (M)
4. Low (B)
5. Very low (MB)

Table I-8. Matrix: Land use vs. vegetation cover

Step 7: Preparation of erosion status map

The erosion map is the final output of the predictive phase, and the result of overlaying erodibility and soil protection level maps.

The overlaying procedure is performed applying the matrix presented in Table I-9.

EROSION STATUS

Level of soil protection	Level of erodibility				
	1(EN)	2(EB)	3(EM)	4(EA)	5(EX)
1(MA)	1	1	1	2	2
2(A)	1	1	2	3	4
3(M)	1	2	3	4	4
4(B)	2	3	3	5	5
5(MB)	2	3	4	5	5

Legend (Codification) of erosive status.
5. very high.
4. high.
3. appreciable.
2. low.
1. very low.

Table I-9. Matrix: Level of soil protection vs. level of erodibility

Sequences of step 7 are shown in Fig. I-11, and the final output is the erosion status map.

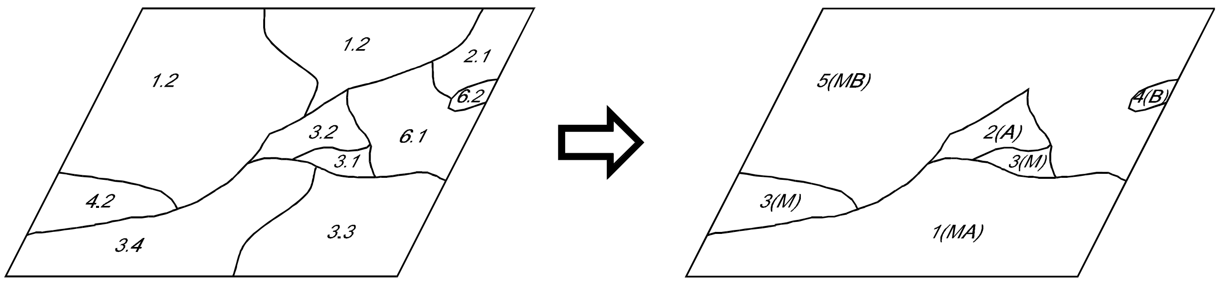


Figure I-10. Soil protection map processing

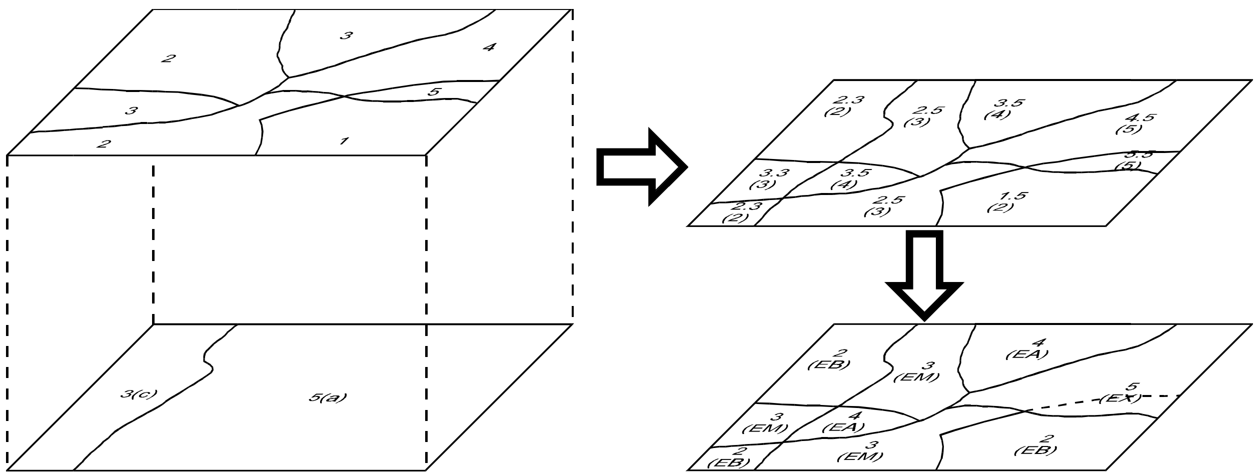


Figure I-11. Erosion map processing

3.3 Second Phase: Descriptive Approach

The implementation of the descriptive approach directly relates to the legend presented in the Chapter 2.2, and in particular in Box 1, point B (site-descriptive mapping).

The descriptive approach consists of the application of the legend to the polygons of the erosion status map resulting from the first phase (predictive approach).

Two elements/procedures are used for such application: photo-interpretation, and field observation. Both are necessary and complementary.

Some of the aspects or categories considered in the legend are rather conspicuous in aerial photographs. Easily identifiable by photo-interpretation are: wastelands (rock outcrops, cliffs, stony or sandy areas), some types of afforestation, physical structures (e.g. terraces), dominant gullies, some cases of mass movements and sediment deposits.

Assuming that overall geographical environments are to be subdivided in two broad categories, i.e. **Stable** non-erosion-affected areas, and **Unstable** erosion-affected areas, continued field observation and erosion process identification procedures consist of several very distinct steps:

- Step 1: For **stable/stabilized** environments defining the grade of erosion **risks/potentials**;
- Step 2: For **unstable** environments defining the type of dominant **erosion process**, its relative **intensity** and **evolutive trend**;
- Step 3: Identifying and assessing specific local features such as main erosion-prone areas or special causative agents.

The above-mentioned procedures are mainly qualitative assessments and are to be considered as complementary to the predictive phase.

Step 1: Defining the grade of erosion risk/potential

- The procedure only applies to **stable**, non-erosion-affected areas which are defined as showing very few or no evident signs of erosion, with well developed topsoil and good soil structure; these areas are usually unused or very lightly/suitably used by man: either the present vegetation cover is adequate and/or topographic and soil conditions prevent erosion.
- Different types of stable and/or rehabilitated areas are identified according to their use, management and grade of erosion risk: the erosion **risk** ranges from 0 (no risk = highest grade of stability) to 3 (stability threshold = highest grade of risk).
- In most cases, the main erosion risk causative agents are easily identifiable; they might be indicated by extra codes as described in Box 1 - Legend.

Step 2: Identifying and defining dominant erosion processes

- All **unstable** areas are affected by one or several erosion processes ranging from slight to moderate and severe degradation which for each specific process can be assessed in relative terms of **intensity** (depth of gullies, volume of soil or sediments removed), or **extension of space affected** (localized, dominant or generalized): adapted codes are given in the legend.

Some practical field observation indicators can be easily identified:

- Slight erosion usually shows some localized surface wash, as a consequence of sheet erosion with a soil loss rate slightly greater than the soil formation rate;
- Moderate erosion clearly shows localized losses of topsoil mainly due to a combination of sheet and rill erosion, particularly on cultivated areas or those covered by scarce vegetation;
- Severe erosion generally removes most of topsoil by sheet and/or rill erosion; gullies have begun to form, fertility as well as the potential land use for many purposes have been seriously affected;
- In severely gullied areas almost all topsoil is removed and more than 50% of the land is gullied and much or all of the affected land may lack any vegetation; these areas are the so-called "badlands" hardly useful for any purpose thus classified as **non-recoverable** areas in the legend (LX, CX);
- Complementary indicators on **erosion dynamics** can be provided through the identification and evaluation of **erosion evolutive trends** expressed by sub-digits as indicated in the legend: either stabilization or expansion and/or intensification of the referred erosion process can be indicated by a sub-digit as described in the legend (see Box 1 - Legend).

Step 3: Identifying specific local features or particularities, such as causative agents of erosion risks for stable environments, multiple and/or associated erosion processes and their main evolutive trends (see Box 1 - Legend).

3.4 Third Phase: Integration

The final map is a descriptive/prescriptive erosion qualitative map containing rather complete information on a number of relevant aspects of the erosion phenomena.

- The final consolidated Erosion Map is the result of associating and integrating predictive and descriptive data in an iterative way using the potential erosion map as a reference cartographic layer which provides a basic grid of homogeneous units where various different erosion processes may occur. The description and mapping of active erosion as well as more specific erosion risks (better identified through their main **causative agents**) are complementary to the predictive cartographic data which implies that final integrated erosion units be expressed by one single comprehensive symbol.
- In **stable** areas grade of stability and erosion risks are identified by the means of the related **descriptive** symbols without referring to **erosion status**.
- Example: 032g = Stable managed area with high erosion risk mainly due to geologic factors
- In **unstable** environments erosion affected units are identified by consolidated symbols integrating both **erosion status** (expressed by the level number figured in brackets)and erosion process (figured by the related descriptive symbol expressing the nature, intensity, extension and evolutive trend of the process); no causative agents are to be identified for actually unstable areas.
- Example:(2) L21 = **unstable** unit with level (2) **erosion status** affected by **dominant sheet erosion** with a trend to **local expansion** or **intensification**.

As a general recommendation, the developed methodology and mapping legend should not be considered as a rigid scheme, but rather as a set of practical guidelines in which cartographic concepts, units and symbols should be flexible and easily adapted to specific geographical country or regional features.

In the descriptive part of the legend the adaptation is possible by opening new categories of processes or features as proposed in the original legend under paragraph 'Multiple Processes" where symbols $^{P1, P2, P3...}$ are available for newly identified erosion forms or trends.

4. IMPLEMENTATION ASPECTS

4.1 Technical Management Components

The application of the represented mapping methodology requires multidisciplinary technical teams. The composition could be as follows:

- 1 specialist in remote sensing (images and processing of data, photo-interpretation) and mapping activities to be fulfilled during the surveying and prospective phases of the programme.

- 1 geomorphologist for the analysis, identification and classification of landscape units and their related morphogenic features and surface water dynamics.
- 1 biogeographer and/or soil specialist for the identification and assessment of various types of both land use and vegetation covers and canopies.
- 1 team leader who should be an expert in soil erosion and be particularly familiar with integrated mapping techniques. He would be responsible for the elaboration of a locally adapted legend and the final integrated predictive/descriptive soil erosion map.

Training at team level should be initiated step-by-step, following the methodological sequences described in the present Guidelines. A second training phase could consist of practical mapping of a small area, preparing the complete sequence of maps and providing a final assessment of both results and problems.

Basic technical data and materials usually consist of the following:

- Complete aero-photographic coverage and/or enlarged satellite images of the study area at scales preferably medium to large (i.e. 1:50,000 to 1:10,000).
- Topographic/hypsometric (contour) maps at scales as near as possible to the scale of aerial photographs and/or enlarged satellite images.
- Geologic/lithologic existing or derived interpreted maps covering the survey area at scales which can be smaller than the basic topographic mapping grid.
- Photo-interpretation material and tools for both office and field work activities (table and pocket stereoscopes).
- Field visits in different periods of the year might be considered in order to take into account variations in vegetation cover and land use as well as extreme rainfall events.

An example of practical application of the proposed methodology is provided by the Adra river basin (726 km²) case study, where the programme of activities was as follows:

1. Basic data and material preparation
2. Preparation of **slope** map and derived **erodibility** map.

   1 Geomorphologist

• Slope map	3 m/weeks
• Lithofacies matrix	1 m/week
• Erodibility map	1 m/week
TOTAL	**5 m/weeks**

3. Preparation of land use and vegetation cover map

• Photo-interpretation	8 m/weeks
• Field control	2 m/weeks
• Soil protection map	1 m/week
TOTAL	**11 m/weeks**

Steps 2 and 3 can be performed simultaneously by different members of the team.

4. Production of the Erosion Status Map by overlapping Erodibility and Soil Protection Maps 2 m/weeks
5. Production of the final Descriptive and Predictive Erosion Map

• Global preliminary photo-interpretation: identification of most evident erosion, processes and planning of field survey	1 m/week
• Field survey. Application of descriptive legend	4 m/weeks
TOTAL	**5 m/weeks**
GRAND TOTAL	**21 m/weeks**

Use of colours

When presenting the maps in colours, the following should be applied:

- stable / non affected areas to be presented in blue or green;
- unstable areas to be presented from yellow ⇒ orange ⇒ light red ⇒ dark red, with progressive growing density of the colour selected (from dots to full colour).

PART II:
MEASUREMENT OF RAINFALL-INDUCED EROSION PROCESSES

1. GENERAL CONTEXT

1.1 Hitherto Experience in the Measurement of Rainfall-Induced Erosion Processes in the Region

The complex nature of the erosion phenomena conditions from the first stage any measurement activity. Which part of the erosion process is going to be measured? Is the interest focused on the on-site process of soil particle entrainment and incipient transport, or are we interested in the sediment delivery of the detached materials through the drainage network? Do we want to monitor channel erosion, characterized by thalweg and bank scour deposition cycles, or, are we even interested in the complete erosion cycle?

A particular, specific, experimental response corresponds to each of these questions. Such response is formulated in terms of the research project, which is characterized by a particular field experimental design and data acquisition programme. It is essential to clarify from the beginning which part of the erosion cycle is the subject of our interest and why.

Naturally, it is the research objective arising from the particular management question that has to be solved, that determines that part of the erosion cycle that will be measured.

Consequently, there are no established rules to guide the design of the experimental facilities and data acquisition programme, which additionally are strongly conditioned by the natural features of the study area.

Nevertheless the experience and the rationale of erosion measurements allows two categories of erosion phenomena measurement to be identified:

a) **On site erosion measurement**, and

b) **System level measurement**.

On site measurement monitors the erosion phenomena at the level of soil processes. It can thus focus on the measurement of splash, sheet and rill erosion.

The typical experimental framework is the erosion plot. Instrumentation consists of a rainfall measurement device, pluviometer or pluviograph, and a sediment measurement device, that collects sediment produced in the plot and generally stores a known portion of it to be measured and eventually analyzed. The most common devices are the multi-slot divisor and the Coshocton wheel.

Erosion nails and micro profile sticks are also used to establish fixed reference points on the soil surface, so that elevation changes can be related to the amount of material removed and eventually deposited on other sectors of the plot, before being collected at the outlet.

System measurement refers to the monitoring of the erosion cycle at the watershed level. In this category are several measurement schemes with different degrees of detail and comprehensiveness of the monitoring of the erosion cycle that is taking place in the selected watershed. From a minimum scheme, that simply records the suspended sediment delivered at the watershed outlet, to a complete experimental design which implies the monitoring of the on-site processes, sometimes in several plot groups inside the watershed, and the measurement of the suspended (wash and suspended load) and scoured (bed load) sediment, there are several possibilities.

The instrumentation used for system level measurement are diverse and are described in detail in Chapter 3.

Naturally no qualification or assessment should be made in reference to the scheme. The more complex and precise schemes are not necessarily the best. The quality of the experimental scheme is strictly related to the research objectives being met and to the capacity to clearly answer the management related questions. The experimental response must fit this requirement. Some questions can be answered through plots (i.e. the sheet and rill erosion occurring in relation to particular types of land-use and site conditions) and some others require a complex network of experimental watersheds to reach only an approximate answer (i.e. the modeling of the sediment delivery, that has to be made in order to make predictions of the amount of eroded sediments reaching a coastal sector).

There are several experimental areas where erosion measurements are currently being made in the Mediterranean. In addition to those specifically related to this project, Vallcebre (Spain), Esen (Turkey) and Oued Ermel (Tunisia), which are comprehensively described in (PAP/RAC-UNEP, 1997), others are currently in operation and up to date in terms of their scientific objectives and instrumentation. Amongst these can be mentioned the experiments at Rambla Honda, Almería (Spain), managed by the EEZA, Estación Experimental de Zonas Aridas, Consejo Superior de Investigaciones Científicas CSIC; El Ardal, Murcia, (Spain), managed by the University of Murcia; Lanaja, Zaragoza, (Spain), managed by the University of Zaragoza; Var and Roussillon, (France) managed by the BRGM; Draix, (France), managed by CEMAGREF; Santa Lucía, Cagliari, Sardinia (Italy), managed by the University of Cagliari; Araba, Veneto, (Italy), managed by the University of Padua; Spata, Athens, (Greece), managed by the Agricultural University of Athens.

Some of the research sites are integrated in networks, as in the case of the Spanish RESEL, (Network of measurement and monitoring of erosion and desertification) which is a co-operative project to maintain, co-ordinate, and harmonise the existing experimental fields. It is coordinated by the General Directorate for the Conservation of the Nature of the Ministry of Environment and integrates 47 experimental fields distributed around the country and managed by 11 universities and 7 CSIC (Spanish Council of Scientific Research) centres.

Experience has shown several problems to appear relatively frequently during the implementation and operational phases of work. Some of these are of a general nature and some others are specific technical problems that have arisen in connection with the experimental design, the operation of instruments and data storage, management and interpretation. Such technical problems are detailed in the Chapters 2, 3 and 4 of this document.

Among the general problems that may arise during the implementation and operation of the experimental areas several must be emphasised.

One of the main concerns in establishing an experimental area is to secure the control of the land throughout the duration of the experiment, either through ownership or by legal agreement. This is a critical factor in a middle- to long term activity such as measuring soil erosion. Stable land ownership, whether public or private, is essential. Public ownership does not always guarantee stable conditions, particularly if two or more contending agencies of government claim jurisdiction; often contention arises because of poor goals, weak justification or inadequate support.

Another aspect to consider is related to the person responsible for the experiment. Too often the researcher who plans and begins an experiment will not remain to finish it, therefore, he must leave a clear record of methods and procedures. Also it is important to appoint a unique specific agency and person in charge of the experimental area. The design and operation of experiments through interdepartmental committees, with no agency or project leader clearly in charge, has invariably led to failed objectives because of confusion about responsibilities and credits arising out of the inevitable cross-purposes between agencies. (Hewlett, 1982).

Another major concern is the size of the experimental watershed. Once more this is connected to the research objectives and the management questions which have to be answered.

The integral monitoring of the erosion cycle requires an area large enough to contain at least the first order perennial stream. Something that might require tens of thousands of hectares in some semi-arid Mediterranean environments, or simply be impossible to achieve. As a compromise solution the watershed should contain at least a clear and defined ephemeral stream where the channel phase of the erosion cycle can be monitored.

The question of the watershed size is also connected with probably the most difficult problem related to erosion measurement in arid and semi-arid lands, i.e. the irregularity of the rainfall regime, and the fact that erosion phenomena increase with the intensity of the rainfall. Large storms with a long recurrence interval, although difficult to measure, are critical in explaining the erosion cycle. The solution to such dilemmas should be sought in the context of each particular experimental initiative. It is frequently necessary to identify the specific classes of discharges that are meaningful to the scientific response that is to be provided.

The size of the plots is obviously also a consideration. Again this should be adapted to the experimental objectives. When possible, it is advisable to use existing standard dimensions. For this purpose the USLE plot provides a "universal" reference.

Data management storage and exploitation could turn out to be a nightmare to the researcher, particularly if he is not the person who initiated the project and the person formerly responsible left an inadequate documentation and record of the work done.

A clear, reliable, updated, accessible and thoroughly documented system of data storage and management is vital for the long-term success of the research.

Finally, a pressing technical problem is the measurement of bedload. Bedload measurement is a matter of great uncertainty in Mediterranean "ramblas", in mountain torrents and in big rivers. If bedload measurement is one of the priorities of the experiment, it exerts a strong control on the whole experimental design; the more so the larger the size of the tributary basin and channel.

From several designs proven in practice, the stilling pond (Hewlett, 1982) and the Araba torrent station (Fattorelli et al, 1986) provide the most effective solutions for total load measurement.

1.2 Justification for Implementing Measurements of Erosion Processes

Soil is the basic resource interfacing most of the ecological and socio-economical processes. This simple statement justifies in itself prioritising the soil in terms of the attention it is given with respect to natural resources conservation and economic development planning.

Soil formation takes centuries, millennia or even longer periods, while soil destruction occurs in years, months, days and even seconds. An instant compared with the time necessary to reclaim it, if this is indeed possible.

The United Nations 1990 Global Assessment of Soil Degradation (GLASOD) study presents the extent of soil degradation in the world. Nearly one sixth of the world's vegetated area has suffered some degree of degradation during the last 50 years. More than three quarters of this degradation is caused by agriculture and livestock production or by converting forest to cropland.

The degradation processes are diverse: salinisation and water logging on poorly managed irrigated lands; compaction caused by the use of heavy machinery; and pollution from the excessive application of pesticides or manure. But erosion is by far the most common type of land degradation accounting for 84 percent of affected areas, according to the cited study.

In this context, the need for clear and accurate soil erosion measurements is critical as a reliable basis for the development of prevention and reclamation plans, particularly considering the fact that soil erosion is a silent and complex phenomenon arising from the combination of multiple factors.

Such complexity is at the roots of the limitation of mathematical models, making them of relatively limited application away from the particular conditions existing where they were established.

Soil erosion measurement provide a similar reliable basis for water resources conservation and planning. Both water quality and the water regime are greatly affected by erosion. The fine soil particles that travel farther in suspension are the most extensive pollutant and serve as a vehicle for other chemicals and organic contaminants. Soil erosion is intimately related to floods, particularly in the Mediterranean, to the extent that any study of flood genesis and prevention in the region should consider the erosion phenomena and requires reliable field data on them.

It has been mentioned that efficient erosion control depends on the knowledge of soil erosion rates and mechanisms. Such needs are particularly felt when dealing with complex phenomena, frequently subject to trivial "solutions" that can cause unforeseen effects. In this sense the erosion measurement is a valuable tool for the design of erosion control measures, through the accurate evaluation of the efficiency of management methods applied in soil protection and reclamation.

In spite of the relatively large attention that has been given to soil erosion measurement, an important gap that can be thoroughly identified is the lack of homologation and standardization of these measurements. It is critical that these be made comparable and completely useful both for national and international purposes.

One of the basic objectives of this project is to establish a feasible, real world and real-scale contribution to the solution of the lack of standardized and coordinated international soil erosion measurements. This must be meaningful in the context of a global environment affected by global processes which require a global, coordinated standardized monitoring as the only way to formulate co-operative and coordinated response that present circumstances demand.

Finally, the basic prerequisites for the organization of erosion measurement activities are present in all of the Mediterranean countries. From the institutional framework to the technical capacity, all the necessary elements are easily identifiable in the region.

2. MEASURING DESIGN

2.1 The Erosion-Sedimentation Sequence

The generic term "erosion" includes a series of natural events, each one being the consequence of the previous one, and affecting all of the parameters to be considered in watershed management. These events, which form a sequence in time, are the following:

- **causative factors of erosion**: chemical action, temperature variations, frost, topography, plant cover and human influence such as: road or railway constructions, industrial projects, mining, sewage wastes, waste dumps, misuse of soils, water and agricultural land. All of these factors, alone or combined, provoke the weathering and the degradation of the surface layers, which are progressively eroded by the impact of rainfall, removed and transported away;
- **erosion** which reveals itself in many different forms: gullying, mass movement of soil or landslides, flood erosion, sheet erosion, stream channel erosion, etc.;
- the **sediment transportation** from the eroded site by a vector such as water, wind, snow, or glacier, etc., to drainage channels and downstream by channel flow;
- the **sediment deposition**, sedimentation or siltation on land, in a water course, lake, or sea, etc. In turn, this last stage can again be the starting point for a new erosion sequence due, for instance, to a change of climatic conditions and/or tectonic events which may reactivate erosion processes remobilizing the formally deposited sediments.

Each of the above events characterising the erosion sequence is a phenomenon which develops in a space having from zero to three dimensions: 0-D point (e.g. location of a sediment deposit), 1-D line (e.g. sediment transport), 2-D surface (e.g. sheet erosion) and 3-D volume (landslide). Each such event is the consequence of previous ones. It is, therefore, understandable why the measurement of "erosion" is so complicated, difficult and rather unreliable. In contrast with other main hydrological variables, such as rainfall, streamflow, snow, etc., the erosion sequence is a one-way process in the human time scale and thus cannot produce two similar events since sediment material sources, once eroded are not renewable. Consequently, the erosion sequence is basically not stable and generates the cause for its transformation, since erosion, in the long run, will transform the site morphology and topography and consequently, its erodibility. This is precisely what takes place very quickly when human pressure on the land results in massive removal of the protective vegetation cover: erosion increases drastically, as well as the sediment transport in river courses; eroded materials build up large sediment deposits downstream; finally erosion declines when bedrock becomes directly exposed and through the removal of all of the erodible surface material and the area becomes sterile for agricultural purposes.

With such a chain of complex and variable phenomena, both in time and in space, one might question how to measure, what and when? The following sections attempt to give an accurate answer to measuring the erosion process.

2.2 Rainfall-Induced Erosion Phenomena

The erosion-sedimentation sequence is complex due to the great number of physical elements, function of both time and space, that conditions each step of the process. In Mediterranean areas, the complexity is emphasized due to the generally greater variability of these elements than in more temperate areas.

2.2.1 Rate of erosion

Extreme runoff events are of fundamental importance in the erosion-sedimentation processes. For example, a drainage channel may serve as a major sediment storage system during a rather long period when moderate runoff peaks cause a progressive rise in the longitudinal profile of the drainage channel system. The incoming sediments are delivered at such a rate that the 'normal' flows are incapable of coping at a sufficient rate, for a variable period of up to several years. When an exceptional flood occurs, a large proportion of the accumulated sediment may be removed at once, and the bed may even be scoured below its previous lowest level. This demonstrates that a correlation between erosion rates and sediment transport in a river downstream cannot be significant over short periods of time, and that there is certainly a varying time lag between the two events. It is likely that the relationships established are much more complicated than simple proportions.

Quantitative determination of the rate of erosion within a watershed has been the subject of intensive research and data collection over many years, but mainly on small trial test plots, often with rainfall simulation. A number of equations and methods of computation have been developed, amongst them the "Universal Soil Loss Equation" (USLE) which computes empirically the quantity of material eroded, usually expressed in weight per unit area per year, as a function of a series of factors including:

- Climate: rainfall intensity, duration and frequency; temperature variability both seasonal and daily; and cycles of frost, thaw, wetting, and drying; etc.
- Hydrology: type and intensity of surface water runoff, assessment of water carrying capacity of sediments at all stages, from rain drops impact (splash) to the rivers and tributaries of the main catchment drainage pattern.
- Geology: rock formations, grade of weathering, hydrodynamic properties;
- Topography: slopes, relief, altitude, etc.
- Plant cover: nature and density of species; seasonal variability
- Human factors: agriculture, urbanisation, engineering works, deforestation.

Analytical studies have so far not reached the point where satisfactory mathematical relationships between rates of erosion and their causal factors can be derived, but some significant trends are, however, apparent in some regions of the world.

Under a basically similar climate, topography, hydrography and soils, small drainage areas with their tendency toward a wide diversity of land use have a greater range in rates of sediment production than large drainage areas. As the drainage area becomes larger, pronounced land-use differences and, consequently, great variations in erosion tend to be smoothed out. Therefore, the range of production rates tends to become smaller. Generally, also, the larger the drainage area the higher will be the percentage of sediment permanently deposited and thus the smaller will be the mean rate of sediment production per unit area, as measured at the drainage outlet of the watershed.

2.2.2 Sediment delivery ratio

The sediment delivery ratio is expressed over a long period of time and is defined as the percentage between the sediment transported by a river and the total quantity of erosion material in movement, both relative to the drainage area at one particular section. Measurements undertaken in existing reservoirs show that the sediment delivery ratio decreases with increasing watershed areas. As an indication, the sediment delivery ratio ranges from 20% to 90% in very small watersheds of less than, say, 2 km^2 and 3% to 15% in watersheds comprised between 100 and 1000 km^2.

Sediment not transported by the stream from the watershed area to the sediment measuring section is deposited in channels, on flood plains, terraces and alluvial deposits. The erosion process and the delivery ratio cannot, at present, be quantified with sufficient precision for project design purposes.

2.2.3 Trap efficiency

The concept of sediment delivery ratio should not be confused with that of "trap efficiency" which is the percentage between the sediments trapped in a reservoir and the total sediments that enter the reservoir. The specification of this ratio is required in order to estimate the rate of siltation of a reservoir by the water and sediment discharges of the drainage system at the site. Trap efficiency depends on:

- the sediment size-distribution, which determines the fall velocity of suspended material and which increases with the size of the particles;
- the time used by an elemental volume of inflow water with suspended sediments to travel from the inlet to the outlet of the reservoir;
- the temporal variability of flow into the reservoir.

Several authors have proposed empirical relationships based on data derived from surveys of existing reservoirs. However, these relationships are rather site-specific as they do not take quantitatively into account the particle size - distribution.

2.2.4 Carrying capacity

The erosion-sedimentation sequence is characterised by:

- hillside/slope erosion processes which provide detrical sediments and colluvial debris to the main collector of the drainage pattern;
- the hydrodynamic processes which evacuate most of the debris depending on the sediment carrying capacity of the drainage network.

Specific characteristics of transported material (specific weight, grain size distribution, shape of particles, etc.) and those of the river bed (roughness, slope, cross-sectional profile, etc.) determine the transport carrying capacity of a river. Transport carrying capacity varies along the course of a river as the velocity distribution changes with cross-sectional variations. It varies also with time at a given cross-section according to the water discharge. When the sediment load is less than the carrying capacity of the river at a given section, the water flow has some energy surplus which is utilised to scour the river bed, provided the characteristics of the river bed material satisfy the transport conditions. On the contrary, if, at a given section, the carrying capacity is less than the actual sediment load, a part of the material is deposited. In general, a river has a trend to scour under high discharge and to deposit under low discharge conditions: this is explained by the variation of the carrying capacity with discharge, and is evident with high turbidity during floods and clean water at low flow.

A river or water course is said to be in hydromorphological equilibrium when the uptake of sediment from the bed is approximately compensated by sediment deposition. On the contrary, a river is unstable when it follows a trend towards equilibrium either by eroding or depositing channel sediments. For example, the Po river in northern Italy has become unstable due to the accretion of its bed in the flat valley, upstream of its confluence into the Adriatic sea. This phenomenon appeared after the bed had been corrected and dykes had been constructed on both banks for flood control purposes. In some stretches of its low course, the river bed bottom has risen with sediment deposits even higher than the surrounding flood plain.

2.3 Measurement Sites

When considering the overall erosion/ transport/sedimentation sequence, two main representative measurement sites have to be identified:

- **Hillside and interfluvee areas**, where land erosion processes generate detrital material and debris; and
- **Main water flows networks and drainage patterns**, where detrital from the slopes is in transit and then deposited by the fluvio-alluvial processes and dynamics.

Many instruments and techniques have been developed for field measurement of the processes of erosion/sedimentation sequences, basically soil erosion, sediment transport and sediment deposition:

- measurements of sediment removed from experimental plots or small watersheds, installed or part of hillside, by surface runoff;
- measurements of sediment transport in water courses, either suspended or moving by dragging and saltation on the streambed;
- measurements of the volume and density of sediment deposits.

Sites suitable to measure the above phenomena are discussed below.

2.3.1 Erosion test plots and small watersheds

Small plots, a few hundred square meters, or small natural watersheds, a few hectares in size, are used to study erosion rates of various soil types which represent a land area of a specific topography and vegetative cover. Plot shape can range from a small rectangular area to a naturally shaped watershed. Plot length should represent the length of slope on which soil losses occur. The length commonly ranges from 10 to 100 m and the width may vary from 2 to 10 m. Heavy metal sheets may be used to delineate small plots. They are easily removed when cultivation of the plots is required. Earthen ridges may be used on plots wide enough to operate equipment normally used in farming operations.

Small natural watersheds usually do not require borders except dikes at the lower edge to direct the flow to the point of measurement.

Plots of all sizes are equipped with a trough or other device to collect the soil-water mixture in the sampling device. Sheet metal is used for the collecting trough on small plots. A concrete channel or earth dike may be used on large plots and small watersheds.

2.3.2 Sediment sampling stations in natural rivers

Sites used as a hydrological station for measuring water discharge measurements in natural rivers are adequate for suspended sediment measurements. In addition to the usual requirements of access and availability, a straight channel reach with rather uniform sediment distribution and velocity is desirable. Consideration is also given to the construction of cableways and bridges and to the installation of the equipment for sampling suspended sediment concentration. As yet, equipment is not available to sample the entire depth of flow in a channel. Depth integrating samplers can only sample the flow from the water surface to about 10 cm above the streambed. This can be an important part of the total water depth under low discharge. Therefore, artificially or naturally turbulent sections which would spread uniformly suspended sediments can provide an approach to total load sampling. Also, for rather small streams, many flow-measuring control structures such as weirs, notches and flumes can be designed to provide some overfall in order to sample the total sediment load of the flow directly into a rather large-size container. Road box culverts and other hydraulic structures may also be used to sample the sediment concentration of a stream discharge.

2.3.3 Artificial reservoirs

Existing artificial reservoirs are often used for sedimentation investigations as they usually act as an "integrator" of the erosion status of the typical land resource area which constitutes the watershed. Studies are generally directed towards determining the quantity, characteristics and distribution of sediment deposits measured periodically by means of topographic surveys of the reservoir bottom. Conventional measurements of sediment inflow and outflow are also required in order to determine the sediment trap efficiency of the reservoir. Essential factors are reservoir size, shape, capacity, inflow and outflow rates and volumes and watershed characteristics.

In order to survey the amount of sediments deposited in the reservoir during a given period (e.g. one year), it should be emptied if conventional topographical instruments are to be used (level, theodolite). Otherwise, a boat equipped with a sonar or with a graduated weighted tape is used provided that the exact position of the boat is determined accurately, either from the boat or from the shore. After survey, the actual topography of the bottom of the reservoir is compared with that of pre-construction in order to determine by difference the total volume accumulated since the date of construction of the reservoir.

2.4 Devices and Instruments for Measuring Sediments

A great number of apparatus and instruments have been developed in attempting to measure each process of the erosion-sediment transport sequence. However, at present, none has proved to be fully satisfactory, reliable and free from disturbing secondary phenomena. Some critical interpretation of the sample analysis by a specialist is always desirable.

2.4.1 Total collection tanks

A **total collection tank** (Fig. II-1) may be constructed to measure erosion in small test plots. The collection tank should be large enough to contain the total runoff (water and sediment) expected in a 24- or 48-hour period. The volume of the water-sediment mixture is then determined and the solid sediment material sampled for subsequent laboratory analysis and computation of its weight and volume.

Total collection devices are often unsuitable because runoff storage requirements may be excessive. Also, very small drainage areas are generally not representative of field conditions.

2.4.2 Slot samplers

To remediate the drawbacks of total collection tanks, slot samplers, which collect a pre-determined percentage of the runoff-sediment mixture, are preferred because they can be used for larger test plots. The sampled volume of water-sediment mixture is then reduced to manageable quantities.

Slot samplers can be used for any erosion studies from small test plots to actual watersheds of several km^2. These samplers are automatic and no observer is required during the sampling operation. Furthermore, sampling can continue under heavy runoff events.

The two main types of slot samplers are the stationary multislot divisor and the Coshocton wheel sampler equipped with a revolving slot.

Multislot divisor (Fig. II-2): Runoff is routed from the collector through a conveyance channel to a sludge tank where the heavier sediment particles are deposited. Overflow from the sludge tank is then routed through the multislot divisor where a sample is obtained from a single slot and routed to a sample storage tank. A second or third sample storage tank may be connected to the first, if additional sample storage is needed.

The **Coshocton-type runoff sampler** (Fig. II-3) collects and concentrates runoff from an erosion test plot or a natural watershed into a collector at the plot end from which it flows into an approach channel. Water discharge from this channel falls on a water wheel, which is inclined slightly therefore causing the wheel to rotate. An elevated sampling slot mounted on the wheel extracts a sample of water-sediment mixture with the representative proportion.

2.4.3 Suspended sediment samplers

Several types of samplers of suspended-sediment have been developed such as trap samplers, direct pumping, integrating samplers, etc. However, only few of them are designed so that the intake velocity into the sampler is equal to the actual stream velocity. This characteristic is essential for the samples to be representative of the suspended-sediment concentration of the stream at the point of measurement. A well-designed sampler faces the approaching flow and its intake extends upstream from the zone of disturbance caused by the presence of the sampler itself.

Instantaneous samples are usually taken by **trap samplers** consisting of a piece of horizontal cylinder equipped with end valves which can be closed suddenly to trap a sample at any desired time and depth.

The **pumping sampler** (Fig. II-4) sucks water-sediment mixture through a pipe or hose, the intake of which is placed at the sampling point. Regulating the intake water velocity in order to be equal of that of the stream, the operator can obtain a sample that is representative of the sediment concentration at the point of measurement.

The **integrating sampler** (Fig. II-5) consists of a metallic streamlined body equipped with tail fins to orient it in the flow. An intake nozzle of an appropriate diameter projects into the current from the sampler head. An exhaust tube, pointing downstream, permits the escape of air from the container which is located in the sampler body. Valve mechanisms enclosed in the head are electrically operated by the observer to start and stop the sampling process.

A new method of *in situ* determination of suspended-sediment concentration is the application of **optical, ultra-sonic or nuclear gauges** (Fig. II-6). The working principle of these instruments is that a beam of light, x-ray, ultra-sound or nuclear radiation emitted by a source with constant intensity is scattered and/or absorbed by the suspended-sediment particles. The decrease of intensity of the beam measured by an appropriate detector or sensor situated at constant distance from the source, is proportional to the sediment concentration, provided other relevant characteristics of water and sediment (chemical, mineral composition, etc.) remain unchanged.

The **automatic suspended sediment sampler** is a system which automatically pumps up water and sediment samples from flowing water, storing up to 24 individual samples. The sampler can be used for routine monitoring and for recording the variation of sediment loads during transient floods.

Manual collection of suspended sediment samples can be a labour intensive and often unreliable method of obtaining data for sediment transport studies, so that automatic suspended sediment samplers are particularly suited for remote sites, or where there is a shortage of trained staff. The automatic sediment sampler can pump sediment suspensions through pipe lengths of up to 10m from flowing water, without altering the sediment concentrations or particle size distributions. It has a variable sampling time, intervals ranging from one a minute to one a day. The sampling schedule can also be programmed to trigger on rising water level for recording during transient floods.

Automatic sediment samplers have been used to monitor soil erosion from small catchments for studies of canal sedimentation, by taking regular daily samples from different depths so that the total sediment load can be calculated.

The **single stage suspended sediment sampler** (Fig. II-7) operates on the siphon principle. It is used to automatically collect suspended sediment samples from flash floods in intermittent streams at remote locations. The sampler consists of a bottle or other suitable container with about Ø 5 mm copper tubes that are formed to a siphon shape and inserted through taps which fit tightly into the tops of the bottles. Several samplers are mounted at various depths on a support that is fixed on the side of the stream so that samples are obtained at several water surface elevations as the water level of the stream rises.

Field experience suggests that sediment concentration obtained with this type of sampler may not be closely representative of that of the stream as the sample is always taken near the water surface during the rising stage, and the original sample may be altered by subsequent submerging. Intake velocities may not be the same as streamflow velocities. Because of these drawbacks, concentration data obtained with these samplers should be used with caution.

2.4.4 Samplers for bed-material discharge

Field measurement of bed-material discharge is difficult due to the erratic sediment movement which takes place in the form of moving ripples, dunes, bars, etc. No instruments have proved to be reliable for trapping the large and small sediment particles with the same efficiency, while remaining in a stable and flow-oriented position on the streambed and not altering the natural flow pattern and sediment movement.

Because of several uncertainties involved in sampling bed-material discharge, it is necessary to determine an efficiency coefficient for each type of sampler. The calibration takes place generally in a laboratory flume, where the bed-material discharge can be directly measured in a sump at the end of the flume, although uniform transport conditions over the width and length of the flume are difficult to maintain. Even under favourable conditions, efficiency factors are not easily determined because they vary according to the grain-size composition of the bed material, the degree of fullness of the sampler, etc. In any case, an efficiency greater than 60 to 70 percent can be regarded as satisfactory.

Available samplers can be classified into three types: basket, pan and pressure-difference.

Basket-type samplers (Fig. II-8) are generally made of mesh material with an opening on the upstream end, through which the water-sediment mixture passes. The mesh should pass the suspended material, but retain the sediment moving along the bed.

Pan-type samplers are usually wedge-shaped in longitudinal section and are located so that the point of the wedge cuts the current. The pan contains baffles and slots to catch the moving material.

Pressure-difference type samplers (Fig. II-9) are designed to produce a pressure drop at the exit of the sampler, sufficient to overcome energy losses, to ensure an entrance velocity equal to that of the undisturbed stream. A perforated diaphragm with a sampler body forces the flow to drop its sediment into the retaining chamber and to leave through the upper exit.

Bed-material discharge is determined from the amount of sediment trapped per unit time in a sampler located at one or more points on the streambed. There should generally be three to ten measurement points in a cross-section. In determining the distribution of sampling points, it has been noted that, except during flood periods, bed-material transport takes place in a portion of the stream width only.

A continuous record of bed-material discharge can be obtained by relating bed-material discharge to stream discharge. Considering the difficulties and shortcomings of the bed-material discharge measurement, computation by relationships based on theory and experiment are frequently used to supplement or control actual measured data, at least to ascertain their order of agreement. In the majority of rivers, the share of suspended sediment is predominant in the total sediment discharge. The percentage of bed-material compared to suspended material discharge is commonly assumed to be about 15 percent.

A rather new and indirect method for determining the bed-material transport is performed with the help of **acoustic detectors**. Submerged to the vicinity of the bed, these detectors pick up the “clicking” sound of moving gravel, indicating the movement of bed material at this particular point. Moreover, the intensity of sound and that of sediment transport may be qualitatively correlated with the size of the particles and their velocity.

Note: The source for Figures II-1, II-2, II-3, II-4, II-5, II-7, II-8, and II-9 is Hudson, N.W.: *Field measurement of soil erosion and runoff*. FAO Soils Bulletin 68, Food and Agriculture Organization of the United Nations, Rome,

1993. For the Figure II-6, the source is Crickmore, M.J., Tazioli, G.S., Appleby, P.G., Oldfield, F.: *The use of nuclear techniques in sediment transport and sedimentation problems*. Technical Documents in Hydrology. UNESCO, Paris, 1990.

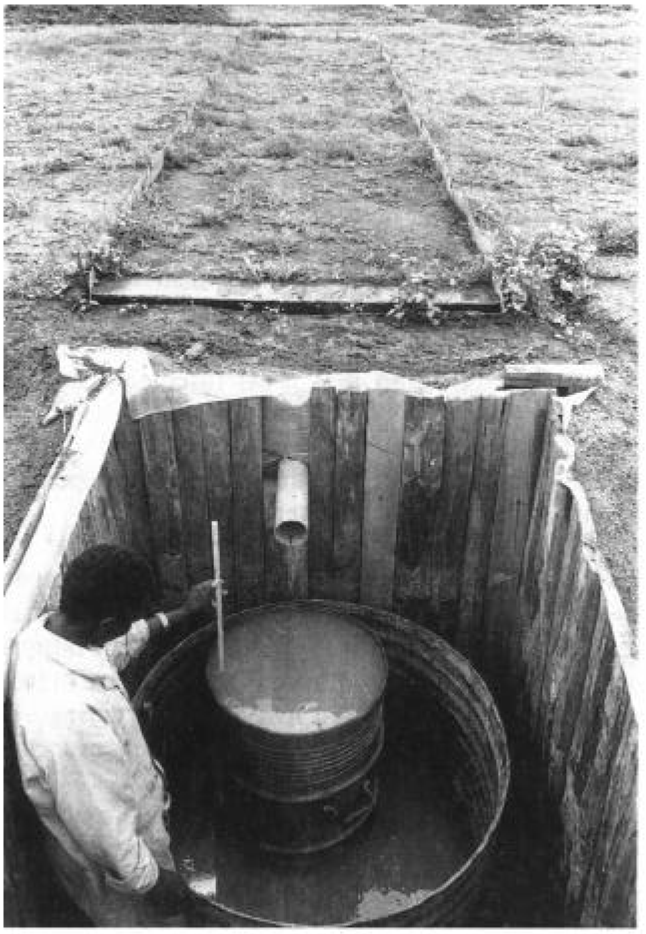


Figure II-1. Total collection tanks

Figure II-2. Multislot divisor

Figure II-3. Coshocton runoff sampler

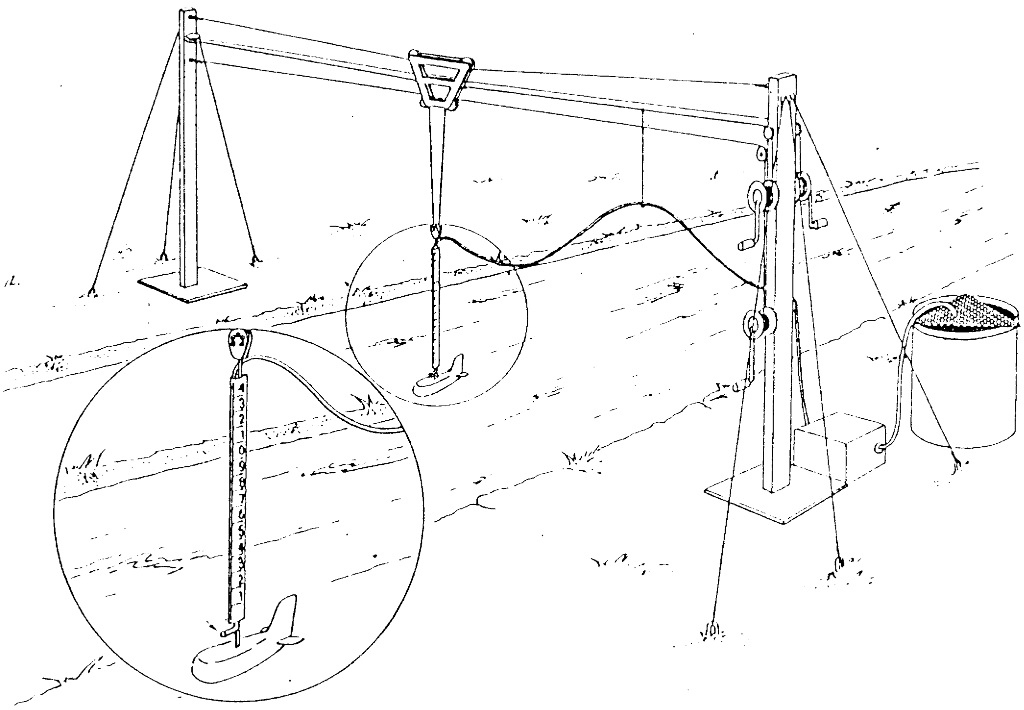


Figure II-4. Pumping sampler

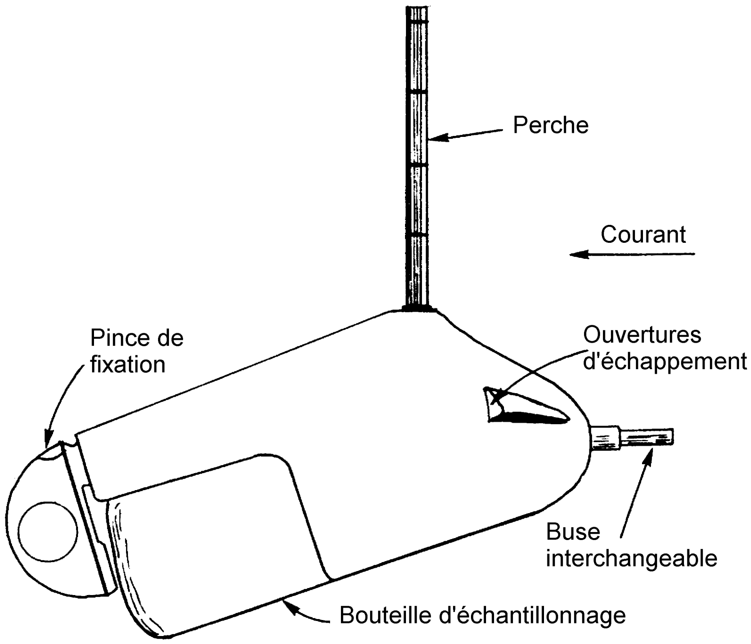


Figure II-5. Integrating sampler

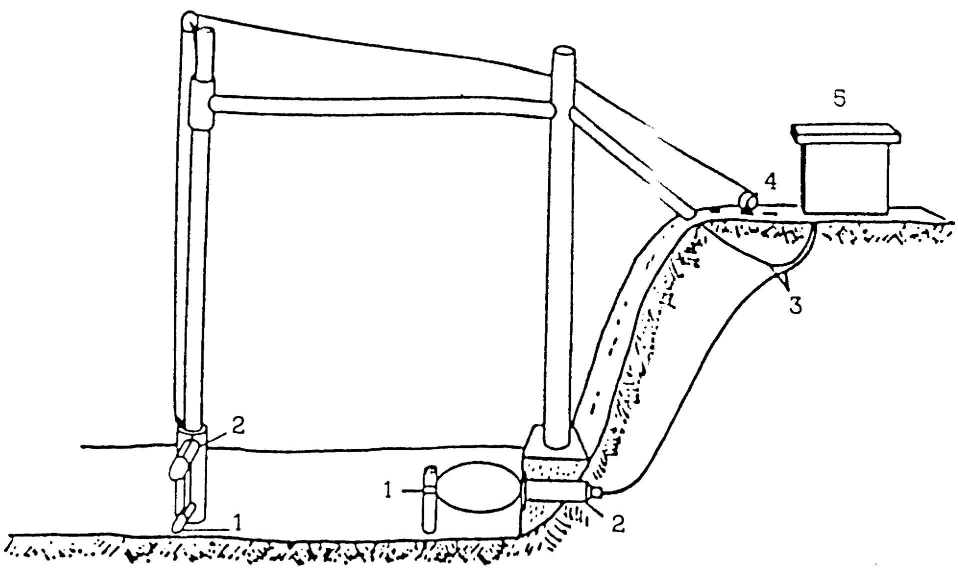


Figure II-6. Suspended sediment nuclear gauge

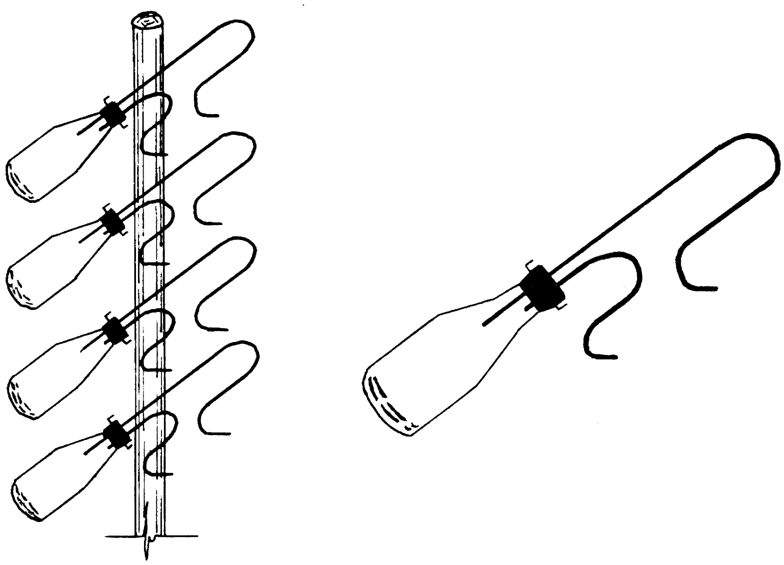


Figure II-7. Single stage suspended sediment sampler

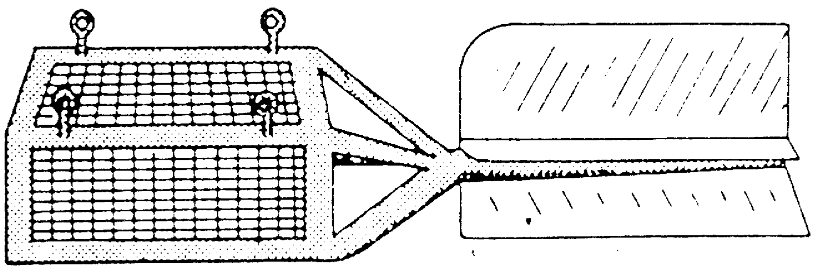


Figure II-8. Bedload sampler

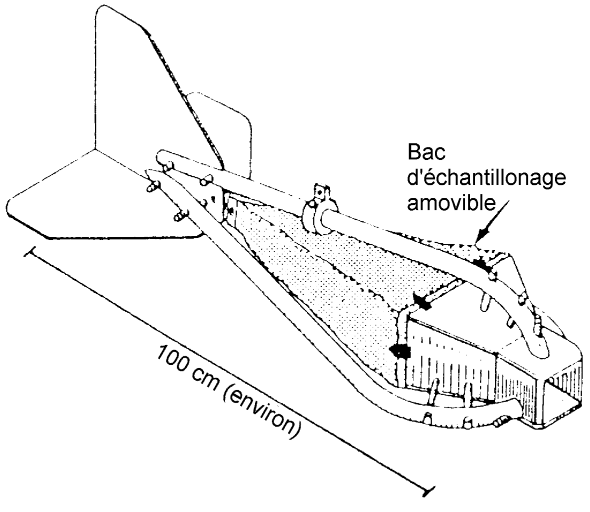


Figure II-9. Bed-material pressure-difference sampler

3. MEASUREMENT PROGRAMME

3.1 Introduction

This chapter is devoted to the description of the characteristics of the measurement programme selected for the development of the Project, including not only the instruments needed, but also practical information of **how to** perform the setting up, the maintenance and the retrieval of information from it.

3.1.1 Design

The Programme is designed taking into account the hydrological and geoecological characteristics of Mediterranean coastal areas, especially:

- The small extent of uniform geoecological units, induced by the high diversity of the geology and topography (steep gradients and contrasted microclimates following aspect) in spite of the low altitude.
- The long history of human land use (degraded vegetation, modified microtopography, man-induced gully systems).
- The occurrence of short intense rainfall events, that can be preceded and followed by long drought periods.

The instrument design is fitted to the measurement of suspended sediment yield, or the particulate sediment fraction smaller than 2 mm. This fraction usually represents the main part of the total sediment yielded by small basins, with relative contributions higher than 80%, and is also the fraction linked to the loss of soil physical and chemical fertility as well as the water quality deterioration (Gregory & Walling, 1973; Hadley & Walling, 1984; Walling, 1988). Nevertheless, the sediment yields from some particular Mediterranean environments, like weathered granitic areas, would fail to be adequately measured by this design.

There are two main aspects to be taken into account about bedload transport by streams:

- The origin of bedload sediments is not usually the same as the source of fine materials. Stream bank erosion instead of soil erosion provides most of the coarse sediments.
- Measuring bedload transport is even more intricate than measuring suspended discharge; it needs comparatively expensive installations that are to be cleaned and maintained after every event.

If there is field evidence of a significant importance of bedload transport, a complementary measuring design should be implemented.

3.1.2 Technology

It is worth stating that, after the experience obtained during the development of the Pilot Project, it was agreed that the best choice would be to base the measuring instruments on the state-of-the-art electronic digital technology. The inconveniences of this choice are mainly related to the presumed lack of experience of the personnel, but this is overcome by the advantages of major autonomy and temporal resolution of the instruments as well as by the immense saving of labour with the use of computerized data management, compared with the traditional hand-based data analysis.

3.1.3 Duration

A measurement Programme devoted to the acquisition of quantitative reliable estimates of erosion and sediment transport rates would need to be designed for a very long period, due to the requirement to sample events of high magnitude and low frequency. Nevertheless, as the main purpose of the Programme is directed towards obtaining a scientific basis for better land management rather than to absolute figures, it can be organized in two steps:

- **An initial phase of up to 3 years**, for selection of sites, acquisition of instruments and implementation of the whole measuring design. This phase needs a wide scientific support in order to secure the best further advantages of work and money investments.
- **A regular programme of 3-4 years**, that can be developed by trained technical staff, but needs also scientific support for the adequate interpretation of results and for monitoring the programme implementation.

This design should ensure the adequate sampling of a range of events that are to be used to understand the erosion and sediment transport processes in the area, useful for guiding management strategies. Long-term erosion and sediment transport rates could be obtained trough the extension of the measuring period or by modelling the magnitude-frequency relationships.

3.2 Recommended Measuring Design

3.2.1 Size of catchments

The measuring programme is based on the monitoring of water and sediment fluxes in a set of **small-sized catchments** (0.5 - 20 km^2). This represents a compromise between a full hillslope approach (runoff plots) and a fully hydrological approach (medium or big-sized drainage basins).

Plot approaches are adequate to calibrate erosion models or to analyze the performance of agricultural or soil conservation practices, but they would be too expensive for obtaining representative information of the actual erosion rates in the study areas. Studies at the plot scale can afford relevant information on erosion processes that would be useful for understanding the behaviour of the systems, but it is very difficult to relate plot-scale erosion rates with sediment yields, mainly because most of the sediments eroded from plots are deposited before reaching the streams.

On the other hand, sediment transport in **large drainage basins** is only fairly or poorly related to hillslope processes, because of the role of the sediment conveyance discontinuities: a significant part of sediments coming from hillslopes is deposited in temporary or permanent sinks, whereas the drainage network itself becomes the main source of the transported sediments. Soil conservation strategies based on measurements of sediment yield from large catchments can therefore fail to reclaim the actual sediment sources (Walling, 1983).

3.2.2 Number and arrangement of catchments

A minimum of a group of three catchments of different sizes is recommended. The catchments should be adjacent, in order to keep comparable characteristics of climate and to allow comparisons at the event scale.

Within a geographically homogeneous area several catchments, each with strongly differentiated land use and/or erosion rates should be considered bearing in mind that the measuring operations provide general trends rather than specific features related to point phenomena.

In most conditions, some of the smaller catchments should be contained within the larger ones (nested structure). This design helps to understand the rules of scale change in sediment transport processes.

This nested structure is highly recommended in areas of high erosion rates, in order to analyze the discontinuities of sediment conveyance (sinks and sources) that could hide the actual erosion phenomena or could be engineered to enhance the natural controls for sediment management.

3.2.3 Geoecological characteristics of catchments

It is recommended to select the several basins as representatives of the main erosion problems in the area. The smaller catchments should be selected to represent rather homogeneous areas either of high or low erosion rates, whereas the wider catchments can include heterogeneous terrain to understand the behaviour of the whole system.

The results of the mapping programme should be used as an indicator for selecting basins in which erosion is to be measured. Nevertheless, it is not possible to obtain an exact match between the two procedures, mapping and measuring. Furthermore, it is important to consider that pure, isolated characteristics are impossible to sample at any scale; the response of catchments being always the result of their characteristics as a whole (size, form, topography, geology, soils, land use, ...).

Pairs of catchments having analogous characteristics (twin catchments) could be considered for instrumentation within an experimental scope. The method envisages a calibration period, to asses the performance of one catchment compared to the other, and an experimental period, when the hydrological and erosion results of land management practices performed in one of the catchments are assessed through comparison with the other catchment, which remains undisturbed as a reference. The meausrement programme could be used as the calibration period, but it will be necessary to continue the measurements after it, during a supplementary measuring period (Toebes & Ouryvaev, 1970).

3.2.4 Selection of measuring points

The location of measuring stations should be selected taking into account the following criteria:

- **Accessibility**: In addition to the work needed to set up the instruments, several hundreds of visits to the measuring stations will be needed during the development of the Programme.

- **Protection** against natural hazards (wildfires, landslides) as well as robbery and vandalism.
- **Hydraulic adequacy**: It is necessary to avoid points where low flows are missed (thick alluvial fills) or where high flows bypass the station (diverting channels or floodplains). The stream reach should be selected as straight and of constant slope as possible. These conditions are to be especially fulfilled if the water balance is to be assessed.
- **Stream floor and bank stability**: Stream reaches susceptible to major changes due to scouring or deposition of bedload or bank erosion should be avoided.

The use or improvement of pre-existing gauging stations is highly desirable in order to take profit of pre-existing information (calibration data, long hydrological records), as well as to make use of customary maintenance schedules.

3.3 Instrumental Equipment

The measurements are obtained through continuous monitoring of water discharges, together with some instantaneous observations of sediment concentrations, through sampling. The instruments needed are therefore the automatic **permanent instruments at the stations** to measure runoff and to take samples, the **portable instruments** to maintain the permanent instruments and to perform runoff measurements as well as sampling during field visits, and, finally, the **laboratory instruments** needed for measuring the sediment concentrations in stream water samples.

3.3.1 Field instruments at the stations

- **Runoff control**: Some structure (concrete or steel made) or natural constriction of the stream channel that provides a unique relationship between stream discharge and water level. More details are given in the header 3.4.
- **Data logger**: An electronic instrument designed to read and store information, following a modifiable programme, with a minimum capacity of two counting channels (rainfall and sampling event marks) and one analogue channel (water level). The memory of the instrument should be sufficient to allow a one-month autonomy with a recording rate of 5 minute-step. It is recommended to use an instrument directly interrogatable by a portable computer, and to be low power consuming device, fed by alkaline batteries, with a typical life longer than 12 months. All the accessories needed to set up and download data from the data logger must be available (*software*, cables and interfaces). The internal clock of the data-logger should be set to the solar time, in order to avoid errors due to seasonal changes of country official times.
- **Water level sensor**: An electronic transducer that converts water level into an electrical signal. It is to be directly fed and read by the data logger itself without the need of other devices or interfaces. There are several kinds of transducers:
  - *Shaft encoders* or potentiometers are electronic instruments connected to classical float-pulley mechanisms for measuring water levels at stilling wells.
  - *Capacitive water depth probes* are electronic instruments which use the contrast of dielectric properties between air and water to measure water level. They are robust and need cleaning only for very dirty waters.
  - *Piezometric sensors* are instruments which measure hydrostatic pressure differences produced by water columns. They are good performance and reasonably inexpensive devices. The main problem with these instruments is that they can malfunction or be damaged after long drought periods.
  - *Ultrasonic instruments* measure water level at a distance. These instruments are the best suited for heavily sediment charged waters, as they do not need any stilling well, but they are somewhat more expensive and need much more electrical source power than the others.

A capacitive sensor is recommended if long dry periods are expected (small streams in semiarid conditions). The model of the sensor chosen must be selected to ensure that all the range of water heights expected are covered and to give readings with an adequate resolution.

- **Sampling instrument**: It is very important to bear in mind that temporal variations of sediment concentrations are very high in ephemeral streams that drain small catchments, and the sampling gaps or mistakes are the main source of errors, which can be by one order of magnitude (Walling, 1988). Because of the ephemeral characteristics of runoff in Mediterranean areas as well as the mistakes that can be introduced in the manual sampling procedures, either or both of two kinds of automatic sampling instruments are prescribed; the choice depends on the economical and security constraints:

- *A programmable pumping water sampling instrument*. It has to meet two requirements: to be triggered by the data logger itself or by a water level threshold triggering mechanism, and to be able to output signals to inform the data logger for recording the exact time of sampling.

  If the instrument is controlled by a water level trigger, the sampling program should be a sequential time type (one sample every time span), the length of the time span being adapted to the expected duration of the event (and also to the size of the catchment).

  If the sampling instrument is controlled by the data-logger itself, the programme of the sampler must be set to sequential flow type, and the data logger is to be programmed to output digital (pulse) information to the sampler according to the water levels recorded (*intelligent sampling*). Another possibility is to perform a flow-proportional sampling schedule; this would be the best solution for obtaining a representative sampling of the transported sediments, but the inconvenience is the loss of information about the processes during the events.

  A small solar panel (250 mA) is necessary to ensure a sufficient charge level of batteries to actuate sampling without weekly maintenance.

- *A siphon-based sampling device* which takes water samples at several water surface elevations as the water stage rises. These instruments are inexpensive, almost free of maintenance, and provide sampling of the rising part of the hydrograph which is usually missed by automatic pumping devices or by manual sampling strategies.

  This instrument consists of a series of bottles (12 units recommended), everyone of them connected to two pipes. The entrance pipe of every bottle has a bend with the form of a siphon, whose height is the main characteristic of this bottle because it controls the height of the surface of the water able to fill the bottle. The exhaust pipes enable air to escape from the bottles when these are filled, the height of their free edge has to be higher than the highest possible level of the water to avoid recirculation of water samples. Both openings (entrance and exhaust) have to be protected against the entrance of the insects with a 2 mm mesh net. (Brakensiek et al., 1979, Walling, 1988).

  If possible, the entrance siphons have to be placed in the same vertical of the control where the water height is measured, to ensure that the discharges reached when the respective bottles are filled is known. If the height-discharge characteristic curve of the station is known, divide the highest discharge by the number of bottles, and calculate the height of everyone of the siphons for every equal increment of discharge; if this characteristic of the station is not known as yet, you can take equal increments of height. The easiest construction solution is to attach the entrance siphons to a wooden shaft, then to secure it in the control section. An 8 mm (or similar) inner diameter flexible tubing for entrance and a thinner one for exhaust are recommended. Five to ten cm are recommended as height difference between the opening and the highest siphon level, depending on the magnitude of the quick oscillations foreseen for the water level.

  The bottles can be one litre plastic ones, numbered starting from the lowest entrance one, and placed in a cabinet protected against vandalism with a key. This cabinet is to be located as near as possible to the siphons, in a low position with the bottles placed more than 20 cm below their respective siphons, and protected against the main water flow. Supplementary bottles and lids are needed to transport the bottles to the laboratory.

  For relatively wide and quiet flow stream reaches, it is necessary to know the relationship between the suspended sediment concentrations in the samples and the mean concentration of the whole flow (Thomas, 1977).

- *Rainfall recording stations*: A minimum of one rain recorder per hydrometric station is prescribed. These instruments consist of tipping bucket magnet-reed contact measuring devices, that can be connected to the same data-logger used for runoff measurements. A resolution of 0.2 mm of rainfall per tip is recommended.

3.3.2 Portable equipment

The enclosed list provides an example of the durable and consumable instruments that are needed to perform the maintaining and sampling visits to the instrumented sites:

- Field books, pencils, waterproof pens, permanent markers (filter pens);
- a collection of bottles with caps for transporting water samples, for every sampler;
- a cleaning flask with distilled water, a cleaning brush for flasks;
- a 10-12 litre bucket;
- a shovel, a basket;
- a 5 kg hand scale (coil type);
- a clock and a stopwatch;
- a kit of tools (screwdrivers, pliers, scissors, measuring tape, etc.);
- a multimeter (voltmeter - ampmeter - ohmmeter):
- a thermometer for water temperatures;
- a 0.5 l plastic graduated cylinder;
- a depth integrating suspended sediment sampler with accessories (rod or cable, reel and crane);
- a portable computer (notebook) with batteries and a waterproof bag;
- cables with plugs or interfaces for connection with the data-logger;
- diskettes for backup copies;
- a current meter with accessories (rod) can be also necessary if the runoff control is not calibrated by design.

The performances of the portable computer must be adequate for handling the software and transmission connection needed by the data loggers (PC AT compatible are sufficient in most cases). Autonomy, weight, robustness and reliability are more important than display quality, speed, as well as memory and hard disk capacity, that are usually the main elements determining the cost.

3.3.3 Laboratory equipment

The laboratory facilities should be adequate for performing routine determinations for sediment concentration of water samples.

The minimal requisites for laboratory durable equipment and consumables are summarized in the enclosed list:

- a water filtering facility, composed by two flasks (input and output), a filter holder, and a vacuum device (electrical or manual), with rubber pipes;
- pincers for handling filters;
- a precision balance, with a resolution of 1 mg;
- an electric heating plate with thermostat;
- a thermometer for water;
- a water electrical conductivity meter (portable if possible);
- cellulose membrane filters (0.45µm pore-size);
- petri slides or containers for individual filters;
- glass 1l bowls (salad-type), heat-resistant;
- 1l graduated cylinder;
- cleaning flasks, cleaning brushes for flasks;
- distilled water, diluted HCl;

3.4 Setting Up of Measuring Stations

The measuring stations will consist of a runoff control where the measuring and sampling devices previously described will be installed. The performance of the measuring station is primarily limited by the behaviour of this control, that is the more permanent device and the more difficult to be modified or substituted.

A runoff control is some man-made or natural constriction of the stream channel that provides a unique relationship between stream discharge and water level, flume or weir type, depending on the range of discharges to be measured, the amount of bedload transport, and other technical constraints. A sediment self-cleaning control is highly advisable.

The size of the control needs to be primarily adapted to measure events up to ten years of recurrence period, medium-sized events being more important than low flows for sediment transport. Controls adequate for catastrophic events are only acceptable if at least two events per year can be correctly measured.

Within the Project, a natural control is only reasonable for pre-existing stream gauging stations in the wider basins, and if calibration measurements are available (stage-discharge relationship). The acquisition of data for a range of discharges is usually a long-term task that could be longer than the duration of the Project itself, and is a difficult task for small basins because of their ephemeral response.

Whenever possible, the flow control structure should be one with a known calibration formula or table (calibration formula or table provided with the design). If field conditions make this impossible, a calibration exercise is to be made, through gauging water discharges with the current meter or chemical methods for a range of discharges as wide as possible.

The control has to be protected against malfunctioning caused by the transport of sediments, especially bedload. This protection can be afforded by a self-cleaning design or by a sediment trap located before the control, sufficiently sized to catch the bedload transported by a medium-sized event. This trap should be emptied as frequently as possible, especially after major runoff events. Self-cleaning designs are highly recommended because an adequate performance of the control during moderate or major events is more important than the higher precision during small events, for sediment evaluation purposes.

The water level is to be measured in a stilling well or pipe, provided with a drainage tap for sediment cleaning. In permanent streams, a pressure transducer can also be placed on the bottom of the runoff control, adequately protected against bedload impacts. The location of the water level sensing device must be selected according to the requirements of the runoff control design.

A graduated shaft should be installed close to the intake of the stilling well or the pressure sensor, in order to check the readings of the data logger with the actual water levels observed by the operator.

The sampling instruments have to be adequately located in order to keep the minimal modification of the hydraulics of the control. Locations with high turbulence of flow are recommended in order to obtain the best mixing of waters, provided they will not be destroyed during high events.

The data logger should be located in a shelter protected against weather and vandalism. Some data loggers are provided with weatherproof housings that behave well if vandalism is not a risk. If the station is provided with an automatic sampler, the best solution is to shelter both the data logger and the sampler in a steel or masonry housing, and to place the solar panel on its roof; this housing can also be very useful in remote locations to store other tools.

Summarizing, the recommended measuring stations should consist of:

- a runoff control:
  - artificial (flume or weir), provided with calibration formula or table;
  - medium -sized (in respect to the size of the catchment);
  - self-cleaning (or provided with an adequate sediment trap);
  - with a graduated shaft for visual readings of water level;
- a stilling well or bottom housing for the water level sensor; and
- a steel or masonry housing to shelter the recording and sampling instruments.

3.5 Field Visits

This schedule has been prepared especially for the following instrumentation:

a) a rain recorder and limnigraph based on a data logger;

b) a stage sampler (siphon fed bottles);

c) an automatic sampler (ISCO 2700 or similar); and

d) a suspended sediment integrating sampler

3.5.1 Every week or more frequently in rainy weather: maintenance of samplers:

The equipment needed is:

- a field book, with a waterproof pen;
- a permanent marker (filter pen);
- a collection of bottles for stage sampler;
- a collection of bottles for transporting water samples from automatic sampler;
- a clock, a thermometer for water temperatures;
- a cleaning flask with distilled water;
- a shovel, a basket;
- a 5 kg hand scale; and
- keys.

The recommended procedure is as follows:

a) Take a new page of the field book and note:

- date and solar time;
- name of the station being visited;
- name of the operator, assistants and visitors;
- height of the water level in the control point (shaft); and
- temperature of the water.

b) Open the stage sampler cabinet and search for filled bottles.

If these are present, take them orderly, plug them, and carefully write permanently on the bottle:

- Station name;
- S + number of the bottle within the stage (S1 for the lowest one); and
- date.

Write on the field book the numbers of bottles recovered (write S0 if none)

Check siphons and pipes, rinse if necessary, but keep the empty bottles dry and clean. Check the protection against insects.

Replace the filled bottles with empty and clean ones.

c) Open the lid of the automatic sampler, and look at the screen to check if it is working and if it has taken some samples.

Remove the control unit and search for filled bottles (one unit less than the flashing number on the screen). If these are present, carefully shake the content of every bottle and transfer it to a transport bottle, plug it and write permanently:

- Station name; and
- A + number of the bottle in the sampler date.

Rinse the bottles and replace them in the sampler.

Write on the field book the numbers of bottles recovered (write A0 if none).

Replace the control unit.

Reset the sampling programme.

Replace the lid of the sampler.

Check cables and pipes.

Check the voltage of the solar panel.

d) Clean and weigh the bedload sediments from the trap or the control, note on the field book the weight and the kind of sediments (cobbles, gravel, sand or mud).

Clear the control and water level devices from any obstruction which could disturb water flowing along the control or the readings of the instruments.

Write in the field book any incidents.

e) Check the funnel of the rain gauge, clean it if necessary, but without water.

f) Close and secure all the doors and locks.

3.5.2 Every month: Data recovering

The equipment needed is:

- a field book, with a waterproof pen;
- a permanent marker (filter pen);
- a clock;
- keys;
- a portable computer (if you do not have one, you have to transport the data logger to the desktop computer, execute the data retrieval instructions, and replace the data logger in the operating station as quickly as you can, to allow minimum data loss); and
- diskettes for security copies.

The recommended procedure is as follows:

a) Take a new page of the field book and note:

- name of the station being visited;
- date and solar time;
- name of the operator, assistants and visitors;
- height of the water level in the control point (shaft); and
- temperature of the water.

b) Open the weatherproof housing of the data logger (remove and transport it if necessary):

- turn on the computer;
- check the validity of the time and date of the internal clock (solar time!);
- connect the data logger to the computer via the appropriate cable;
- start the transference program;
- select the appropriate name of the scheme (station);
- check the file with the data recovered;
- reset the data logger;
- check the correct functioning of the connected sensors;
- quit the transference program;
- make a backup copy of the recovered file;

- disconnect the data logger from the computer and turn off the latter;
- write on the field book all the incidents.

3.5.3 During discharge events: Direct sampling

This task is not a routine procedure; it needs to be much more adapted to field and event conditions and, therefore, requires a more experienced personnel. As it is to be performed during discharge events, it is especially important to prepare all the necessary steps of the operation before starting the task, and not to take personal risks.

If stage and automatic samplers are in operation at the station, this task is first necessary to know the relationship between the sediment concentrations of samples from these devices and the mean actual discharge of the whole flow. If no automatic sampler is active, this is the main procedure to obtain suspended sediment data.

In both cases, the first strategy is to obtain measurements of suspended sediment concentrations characteristic for a wide range of flow conditions (discharge, rising or decreasing flow), then the **sampling interval is to depend more on discharge variations rather than on time**. A further strategy is to obtain a large number of sediment concentrations throughout the events.

The equipment needed is:

- a field book, with a waterproof pen;
- a permanent marker (filter pen);
- a collection of bottles to transport samples;
- a clock, a thermometer for water temperatures;
- a 10-12 litre bucket;
- a depth integrating suspended sediment sampler with accessories (rod or cable, reel and crane); and
- a cleaning flask with distilled water.

The recommended procedure is:

Small (less than 2 m wide) and turbulent reaches, or transparent waters:

Under these conditions, use the bucket to collect one or two samples that you consider representative of the whole suspended sediment discharge, shake well and take a sample in a bottle for laboratory analysis, seal it, and carefully write permanently on the bottle:

- B (for bucket sample);
- station name;
- date;
- time; and
- height of the water at the control point.

Take the field book and note in it for every sample:

- bucket sample;
- station name;
- date;
- time;
- height of the water at the control point;
- height of the water at the stage sampler (if different);
- rising or falling water discharge;
- water temperature; and
- your name.

Wider (more than 2 m wide) or low turbulence reaches:

Under these conditions suspended sediment concentrations can significantly vary in depth and position within the stream section. It is necessary to perform a rather intricate operation to obtain a representative sample.

There are several sampling strategies which can be used depending on the needs and the experience of the team; the easiest one, which produces results adequate for our purposes, is the so called "equal transit rate method" (see relevant Turkish case study in (PAP/RAC-UNEP, 1997)). This method is based on the fact that the intake velocity of the sampler is proportional to the flow velocity, then, if the sampler is moved along several verticals equally spaced in the cross section, at the same transit rate, a single sample can be obtained, representative of the mean suspended sediment concentration (discharge weighted) of the flow.

a) Select a section of the stream near the gauging control where the cross section is somewhat constricted and fairly uniform in depth. Determine a number of equally-spaced verticals along a cross-section of the stream, depending on its width (6 to 12 typically).

b) Place the suspended sediment sampler in the central vertical, and move it at continuous rate from the surface of the water to the bottom of the channel and reverse. Open the sampler and check the sample taken in the bottle: if it is filled one half to three-thirds of its capacity, the rate of movement is adequate; take a faster rate for a more filled bottle, or a slower one for a less filled bottle.

c) Make a transit on every one of the verticals at the selected movement rate, and pour every sample into the bucket (you can also change the sampling bottle).

d) Shake the content of the bucket well and fill a transport bottle with this averaged sample. Write permanently on the bottle:

- D (for depth-integrated sample);
- station name;
- date;
- time; and
- height of the water at the control point.

Take the field book and note in it:

- Depth integrated sample;
- station name;
- date;
- time;
- height of the water at the control point;
- height of the water at the stage sampler (if different);
- rising or falling water discharge;
- water temperature;
- number of verticals; and
- your name.

e) If you want to calibrate the automatic sampler, open its lid, note the number of the bottle to be filled in the field book, press the "HALT PROGRAM" key, then the "MANUAL SAMPLE" key, wait for the sampling operation to finish, and press the "RESUME PROGRAM" key. Replace the lid of the sampler.

3.6 Laboratory Work

It is necessary to perform at least the following determinations with the samples obtained during the former procedures (Hadley & Walling, 1984).

3.6.1 Total suspended sediments concentration

Weigh the sediment retained on a 0.45 μm filter. The filters have to be weighed before filtering, and, after filtering, dried at moderate temperature (4O° C max) and weighed.

Transparent water requires the filtering of the whole sample, but only a small part of it (mix well!) is enough for more sediment-charged samples, to avoid saturation of the filter.

Express the result in milligrams per litre (net weight of the filtered sediment divided by the volume filtered). Label the used filters and store them in a dry cool place for eventual subsequent analysis.

3.6.2 Total dissolved sediments concentration

The electrical conductivity of the water is measured with a customary EC meter. At the same time, it is necessary to measure the temperature of the water and calculate the correction to be applied to the electrical conductivity in order to make it equivalent to the one prevailing at the standardized tempareture of 25° C

To convert EC readings into dissolved sediment concentrations it is necessary first to construct the relationship, by obtaining the dissolved sediment concentrations by weighing the dry residue at moderate temperature (40° C max) of the water obtained by the previous filtering procedure.

Express the result in milligrams per litre (net dry residue divided by dried water volume).

3.6.3 Other determinations

If the laboratory incorporates the appropriate facilities, it is advisable also to perform analysis on:

- grainsize analysis of suspended sediment (laser scattering, pipette or densimeter analysis).
- mineralogical and chemical analysis of filtered sediments (by X-ray Diffraction and X-ray Fluorescence).
- pH, alkalinity and major dissolved ion concentrations.

4. DATA PROCESSING AND PRESENTATION

4.1 Benefits from the Measurement Programme

It has been claimed that a lack of reliable information on erosion and sediment yield rates for large parts of the world exists, and that this lack is a major inconvenience to assessing the environmental consequences of erosion, as well as to designing adequate erosion control strategies (Lal, 1988).

This lack of reliable information is due to the fact that measuring erosion rates is an exercise subject to several and important sources of uncertainty that increase under semiarid conditions where runoff is ephemeral or highly varying. This uncertainty reoccurs throughout the measuring programme; it begins with sampling stream water and ends with the calculation of annual sediment yields.

The quality of the data obtained through this programme depends primarily on the adequacy and accomplishment of the sampling programme, but also on the data processing routines used. It has been shown that the use of different calculation procedures on the same data sets can give final results of sediment yield that differ by one order of magnitude (Walling, 1988). The purpose of this chapter is to provide a set of recommendations to process the field and laboratory information for assessing sediment yield volumes for individual events and for the whole measuring period; some instructions are also given for preparing the technical and management-oriented reports.

It is important to highlight that the present measuring programme seeks to obtain reliable information on erosion rates and sediment yields from small catchments, sufficient for understanding the erosion processes active in these areas and to orientate land management strategies and erosion control practices. Its development will provide information on the characteristics of events as well as an assessment on the sediment yield rates, together with some knowledge on the degree of uncertainty of this estimate. Very probably it will not provide "official" erosion rates that would appear authoritative, but it should provide reliable and, therefore, useful information.

4.2 General Aspects of Relevant Data Management

4.2.1 Sources of error

The assessment of erosion and sediment transport rates is a task subject to major difficulties and severe errors. It is worth emphasizing that such errors can be typically of one or two **orders of magnitude**. There are four main sources of errors in estimating sediment transport in streams:

a) **Quality of samples.** During the transport process, sediment particles experience their own dynamics that are not exactly the same as those of the water mass: particles continuously fall due to gravity, and are uplifted by the turbulence of the flow. This means that sediment concentrations can be very different within the flow section, and that any instrument placed within the flow will modify its local dynamics. Furthermore, some dilution or concentration of the sediment can be produced through the sampling process or during the handling or fractionating of the sample (Hadley & Walling, 1984).

b) **Representativity of samples.** The sediment concentrations at the same place are usually subject to strong variations in time. These variations are usually linked to the variations of water discharge but the relationship is usually nonlinear and subject to hysteresis phenomena. The temporal change in sediment concentration and the non linearity of its relationship with water discharge increases with the decreasing area of the basin (Walling, 1988).

c) **Interpolation and extrapolation of samples.** Because the sediment concentration is obtained for instantaneous samples, it is necessary to use some interpolation or extrapolation procedure to estimate a continuous sediment concentration that multiplied by the water discharge will give the sediment discharge (Walling, 1988, Walling & Webb, 1981).

d) **Temporal integration of solid discharges:** The temporal irregularity of sediment concentration and the non linearity of the relationship between sediment concentration and water discharge can be a major cause of error during temporal integration of solid discharges.

The Measuring Programme has been designed to minimize the errors introduced due to the first two mentioned sources of errors by an appropriate sampling design, taking into account the experience gained during the PAP/RAC pilot project. The third source of error could be avoided by making the minimum use of interpolation and extrapolation exercises, through obtaining a sufficient number of representative samples with the help of the automatic sampling. The fourth source of error is to be overcome by using the shorter time-step of integration possible, typically 5 minutes for small ephemeral catchments.

Nevertheless, it is important to bear in mind that neither do data series without errors or gaps exist, nor are perfect interpolation-extrapolation procedures available.

4.2.2 Interpolation and extrapolation

It is very difficult to prescribe easy-to-use rules for data interpolation and extrapolation because the objective of the Programme is not to obtain "official" data that would appear authoritative, but to provide reliable tools for analyzing water and land conservation strategies.

An outstanding example of one of these problems has been provided by the PAP/RAC pilot project, through the work of the Turkish team (PAP/RAC-UNEP, 1997). This example shows that the same information obtained through a sampling strategy can give very different sediment transport rates depending on the method used for interpolation and extrapolation.

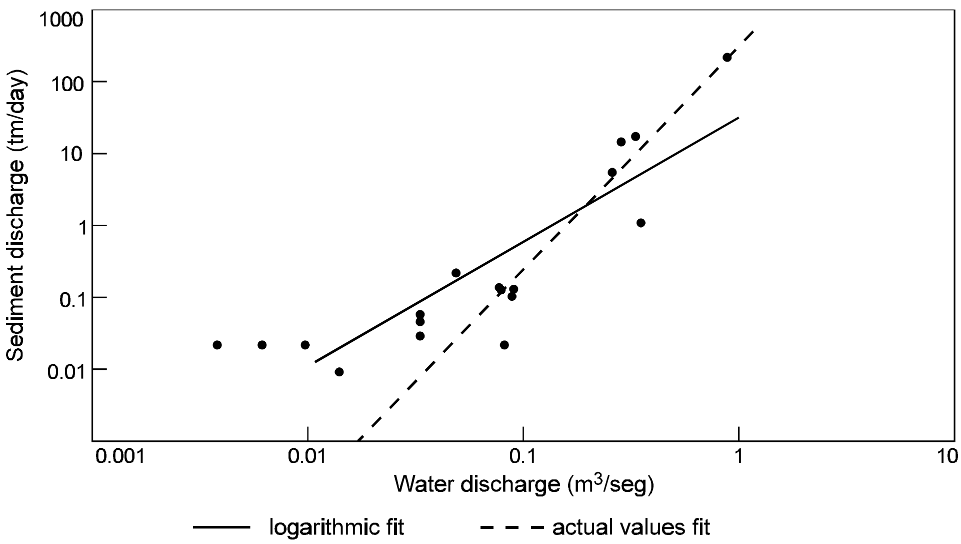


Figure II-10. Relationship between instantaneous sediment and water discharge obtained through sampling at the Çenger station, Turkey
Source of data: Dogan & Sevinç, 1995

Figure II-10 shows, on a log-log graph, the instantaneous sediment transport rates obtained through field operator sampling in the Çenger station during the PAP/RAC pilot project, together with the "sediment rating relationship" customarily obtained by the log-log linear regression, and another regression line obtained by minimizing the residuals of the actual values instead of the logarithmic values. It is evident that the first regression gives a much better fit than the second one on this graph.

The two regression lines were obtained by minimizing the residuals of the logarithms and the residuals of the actual discharge values respectively.

Nevertheless, Figure II-11 shows the same data and regressions on a linear graph, demonstrating that, if the customary logarithmic fit is used, we can miss the information provided by the highest value of sediment transport observed.

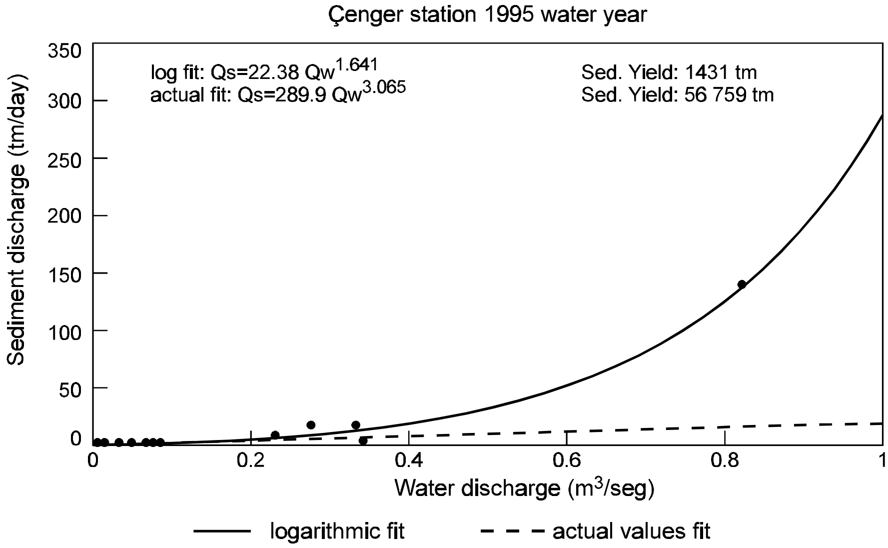


Figure II-11. Relationship between instantaneous sediment and water discharge obtained through sampling on a linear scale at the Çenger station, Turkey

The same data and regressions of the former figure, but on a linear scale. The logarithmic regression gives an extreme underestimation of the major events, which play the major role in sediment transport. Note that the sediment transport estimated with the logarithmic regression is about forty times less than the transport estimated with the actual values regression, *for the same data set.*

In this case, using the same field data and calculation steps but different curve-fitting techniques, we obtain either **1,431** or **56,759** metric tons of sediment yield for 1995: a 1/40 ratio! This shows also that there is little value in using a large number of significant figures or decimals in the results: it gives a false impression of precision.

It is worth emphasizing that if the logarithmic regression is fitted to a subsample composed by the 10 points with a water discharge higher than 0.05 m^3/s, the resulting regression takes the form $Qs = 236.7\ Ql^{3.074}$, and the resulting sediment yield for the year is 46,776 tm, a value comparable to the estimate obtained with the equation fitted to the actual values. The problem is that this third procedure is subject to some degree of subjectivity, but it can avoid significant errors.

The recommendation is to use a curve-fitting technique which minimizes the residuals of the actual (non logarithmic) values. If this is not possible, it is necessary to check the adjustment of the fitted curve on a linear graph, and to select subsample sets or to weight the samples with their values (every sample being represented by *n* observations, where *n* is its sediment transport value) in order to obtain a good adjustment to the actual data.

4.2.3 Event analysis and temporal integration

The small size of the catchments as well as the ephemeral regime of the streams makes it necessary to perform detailed analyses of the events. An excellent example is provided by the Tunisian team during the Pilot Project (Boughrara, 1994), through the data represented in Fig. II-12.

The first comment suggested by this graph is the importance of the sampling frequency during such an event: one sample per day would be of very little value.

This kind of event needs a detailed analysis in order to obtain the appropriate information not only on erosion and sediment transport rates, but also on the processes active in the catchment.

Qualitative analysis: Fig. II-12 shows that water discharge somewhat *precedes* sediment concentration. This behaviour, for a small catchment, suggests that the sediment is mainly produced from the hillslopes: there is not a 'bulldozer' effect of the rising flood on the stream channel. It can also suggest that the main sediment sources are located in the headwaters. Finally, the sustained high sediment concentration during the recession suggests that the erosion is limited by the rainfall and overland flow energy: available sediment is not exhausted. These seem to be very fine sediments that do not need high flow velocity to be maintained in suspension.

Quantitative assessment: Because of the very good sampling of this event, interpolation - extrapolation procedure can cause only minor errors. Nevertheless, the strong temporal variation of sediment transport can generate significant errors due to the temporal integration of the solid discharge.

A standard procedure used by hydrologists to assess water resources is the accumulation of daily flows. Nevertheless, when water discharge and sediment concentrations suffer wide daily oscillations, sediment discharges are to be integrated at the shorter time step available, before the daily accumulation, otherwise this procedure can produce very important errors. In this example, the "flat" integration of daily flows before computing sediment discharge would be the main source of error, as shown in Table II-1.

This table demonstrates that different temporal integration procedures, for the same interpolation procedure and data set, can lead to **350** or **0.120** tm of sediment yield, this is about a 1/3000 ratio. This is due to the fact that the sediment transport-water discharge relationship is a curve, and the average of the Y values is different to the Y value that corresponds to the average of X values.

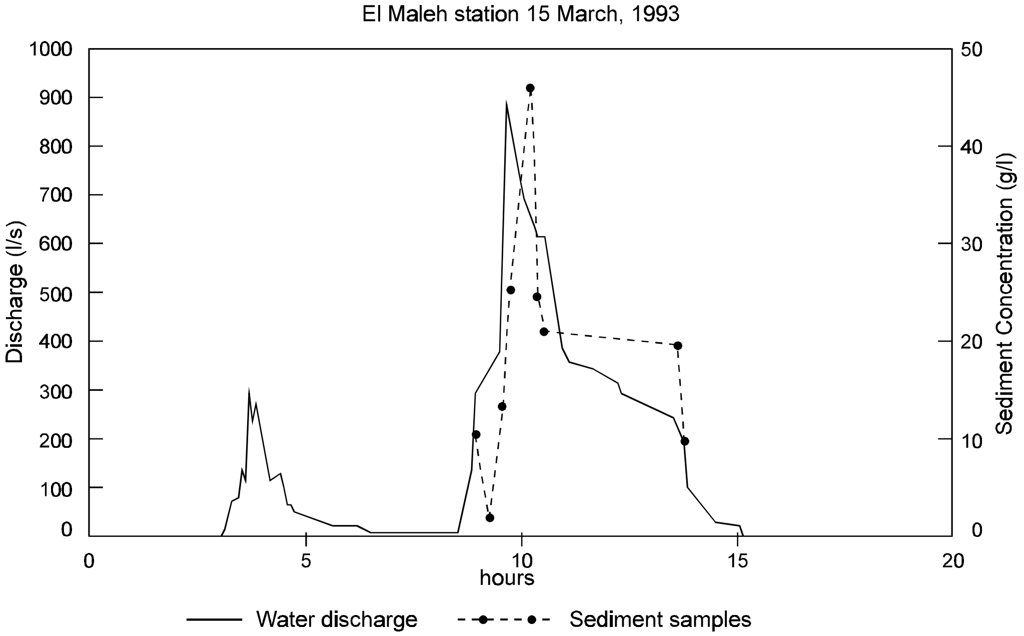


Figure II-12: Hydrograph and sediment concentrations obtained at the El Maleh station (Tunisia) during the event on 15 March 1993

Observe the high variation of discharge and solids concentration during the ephemeral event (Source: PAP/RAC-UNEP, 1997)

Samples	actual values fit		logarithmic fit	
	5 min step	**daily flow**	**5 min step**	**daily flow**
all	174 tm	73.6 tm	132 tm	32.6 tm
set A	337 tm	0.179 tm	350 tm	0.12 tm
set B	183 tm	131 tm	192 tm	152 tm

Table II-1. Sediment yield estimates for the event on 15 March 1993 at the El Maleh station

Computed after twelve different procedures regarding sampling (all samples or two subsample sets), curve-fitting technique (actual values or logarithmic values), and temporal integration of sediment-discharge rating formula (5-minute step or daily integration). Temporal integration can introduce a much wider error than interpolation procedure or sampling design.

4.2.4 General recommendations

The data handling and presentation procedures within the measurement project should provide:

a) A description of the original data obtained through the sampling programme, that include place, date and time, sampling method, water stage and discharge at the sampling moment. This is necessary in order to **check the possible errors or mistakes** in the sampling or measuring procedures.

b) A detailed analysis of some of the more representative events, especially to show the detailed hydrographs as well as suspended sediment concentration / liquid discharge relationships. This is necessary in order to analyze the main aspects of the erosion and transport processes active in the basins, in other words, to **analyze the qualitative aspects of erosion and transport phenomena**.

c) A detailed description of the steps used to interpolate and extrapolate the instantaneous sediment measures, as well as the procedure used for temporal integration of water and sediment discharges. Whenever possible, alternative methods of both procedures should be tested and presented in order to know the range of errors in the resulting estimates.

d) A description of water and sediment discharges that would contain an assessment of likely errors and make possible the analysis of temporal or seasonal differences.

e) A recapitulation of the information and findings relevant for subsequent usage by scientists, engineers and policy makers. This would include the statistics of the data obtained (water discharges, sediment discharges with an assessment of the errors, characteristic sediment concentrations in stream waters), as well as the main aspects of the goals and the problems suffered during the Programme (number of samples, total time of measured discharges, main problems with instruments, and directions to improve the method).

4.3 Data Processing, Formats for Data Recording

4.3.1 Kinds of data to be processed

There are several sources of information from the measurement programme:

- continuous precipitation, water stage height, and timing of automatic sampling, from the data-loggers. These are typically in the form of 5-minute step or variable-time step computer files that allow a full computerized processing, with excellent advantages compared with the traditional hand-graphic processing.
- instantaneous water discharge measurements made by an operator with current-meter or chemical methods. These data are identified by date and time as well as water stage.
- instantaneous sediment concentrations during the rising limb of the hydrograph, obtained through the analysis of samples taken by the stage samplers. These data are identified by the corresponding water stages in the rising limb of the hydrograph.
- instantaneous sediment concentrations during flood events, obtained through the analysis of samples taken by a programmable automatic sampler or manually by an operator. These data are identified by the date and time recorded by the data-logger or the operator.

4.3.2 Steps for data processing

There are two kinds of information during the data processing: *actual data*, obtained from the four sources listed in the former paragraph, and *derived data,* obtained through some computation with a stage-discharge relationship or a water-sediment discharge rating formula. Original actual data are to be protected against loss or deterioration, and derived data are to be considered as open to improvement, if better relationships are obtained during the programme.

The steps needed to process data are the following ones:

a) **Establishment of 'stage-discharge' relationships or rating formulae for the gauging stations**. The recommendations of the former chapter are that these relationships should be provided by the designer of the runoff control, if these are artificial controls, or by the water authorities, if these are pre-existing runoff stations. If these recommendations cannot be fulfilled and new control stations with unknown rating formula are set up, the best solution is to take some usual formula (critical flow, Manning-Strickler...) with provisional parameters, and to improve it during the measurement programme through performing flow measurements with a current meter for a range of discharges as wide as possible. Nevertheless, it is worth stating that stage-discharge relationships do not provide usually the main source of errors for estimating sediment yield.

b) **Establishment of chronological data files containing raw data from the data loggers and derived data computed through calibration or rating formulae.**

This is recommended to be made by using some computer spreadsheet *software*, like EXCEL or LOTUS 1-2-3. These files should be set up shortly after data retrieval in order to check any malfuntioning of instruments, but early files can be updated or improved if necessary with sediment rating formulae obtained later during the Programme. Time integration of water and sediment discharges are to be made in the same spreadsheets at the data-logger time step.

Establishment of sediment discharge versus water discharge relationships. It is first necessary to determine the sediment concentration of the samples, and to attribute a date, time, water stage and water discharge to every sediment concentration. The analysis of the sediment-discharge relationship, that may be made with the help of a computer spreadsheet, is crucial for understanding the erosion and transport processes as well as for obtaining an adequate sediment rating procedure that will allow a reliable assessment of sediment yield. Using a unique sediment rating formula for all the water discharge values obtained at a station should be avoided within the Programme, because errors could be very important. The best solution would be to use two different sediment rating formulae for the rising and recession limbs respectively of every significant event, obtained from sediment data collected for the same event. Simpler solutions could be to use rating formulae adapted to different seasons and hydrograph limbs.

origin>	operator	clock data logger	clock data logger	shaft data logger	gauging	laboratory	laboratory	laboratory	calculated	calculated	calculated	calculated
description>	sample n.	date	time	stage	discharge	suspended solids conc.	electrical conductivity	dissolved solids conc.	discharge	dissolved solids conc.	suspended solids disch.	dissolved solids disch.
symbol>				H	Qm	Cs	Ec	Cdm	Q	Cd	Qs	Qd
units>		dd-mm-yy	hh:mm	m	m3/s	kg/m3	mS	kg/m3	m3/s	kg/m3	kg/s	kg/s
	1	-	-	-	-	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-

Figure II-13: Example of spreadsheet for handling sampling data. Sample order should be kept in chronological order, in order to allow the study of the likely hysteresis behaviour. A column can be added for remarks.

d) **Production of temporal graphs of instantaneous precipitation, water discharge, suspended discharge and dissolved discharge for the whole period of acquisition, as well as more detailed graphs for the main relevant events.** Production of tables with the time-integrated volumes of precipitation, runoff, suspended sediment yield and dissolved sediment yield for the main events, total period of acquisition and annual area-averaged rates.

4.3.3 Sample data spreadsheets

There are two different kinds of data to be handled with the help of spreadsheets: **sampling data**, obtained by hand or automatic sampling, and **chronological data**, obtained by the data-loggers.

Sampling data*:* Figure II-13 displays an example of the recommended procedure to handle sample data on a computer spreadsheet. This spreadsheet can be also used to analyze and to build the relationships stage - discharge, electrical conductivity - dissolved concentrations, and water discharge - sediment discharge.

Nevertheless, the usual spreadsheets do not allow the study of a wide range of curve-fitting techniques, and the usual way to fit a potential function is the linear regression of the logarithmic values. In these conditions, the best solution is to perform the following steps, *for every separate event*, if possible:

a) Make two columns with the logarithms of water discharges and solid discharges (product between water discharge and sample solids concentration) corresponding to all the available samples.

b) Build the XY graphs for actual water and sediment discharges as well as for the logarithmic values, keeping the chronological order of sampling. Study the hysteresis loops and the relative significance of every sample in the total transport (actual values). If hysteresis phenomena are significant, make the following steps for every different part of the hydrograph (rising and recession limbs usually).

c) Compute both linear regressions with actual and logarithmic values, build three new columns with the predicted values from the two regressions and with the anti-logarithms of the values predicted by the logarithmic regression, display them on the respective graphs.

d) Compute and cumulate the differences between measured and predicted sediment discharges, using the anti-logarithms of the log-log regression. If the difference is considered too big, select a smaller number of samples (usually the problem is that there are too many samples for very low discharges), and repeat the former step (c).

e) Select the set of the more adequate regressions for predicting sediment discharges, the more intricate solution being a different equation for every part of the hydrograph of every event, and the more simpler one, a simple regression for all the observed data. Establish a table with the differences observed with the several methods (see Table II-1).

Chronological data files cannot easily be handled with a spreadsheet if all the month is represented by a 5-minute step (a constant step data logger is used). There are two solutions to this problem: rows with repeated values of stage height without rainfall or sampling data can be deleted, or 15-days periods of full 5-minutes step are used. Temporal integration of water and sediment discharges must be given in the same spreadsheet, by multiplying instantaneous discharges by the time interval between readings (rows).

origin>	clock data logger	clock data logger	clock data logger	calculated	level sensor data logger	rain gauge data logger	calculated	calculated	calculated	calculated	calculated	calculated
description>	date	time hours	time minutes	rows time interval	stage	rainfall	discharge	suspended solids disch	dissolved solids disch	runoff	suspended transport	dissolved transport
symbol>				dt	H	P	Q	Qs	Qd	R	Ts	Td
units>	d	h	min	s	m	mm	m3/s	kg/s	kg/s	m3	tm	tm
	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-

Figure II-14: Example of spreadsheet for handling chronological data logger information. A supplementary column can be added for remarks.

Figure II-14 displays an example of the spreadsheet that can be used for handling chronological data. Sediment discharge and transport columns can be made for alternative sediment rating equations. A row at the end of the sheet can be added for total cumulated volumes of water and sediment.

4.3.4 Formats for progress reporting

Progress reports should fulfill the requisites listed in the header 4.2.4 of this chapter. The main aspects to be fulfilled are:

Text:

The main text of the report should summarize the main aspects of the work carried out within the measuring Programme, especially:

a) Instrument set up dates and periods of data recording for the several stations. Record gaps occured.

b) Summary of the samples obtained as well as flow measurements performed by the operator, if any.

c) Description of the main events that happened and the water and sediment discharges observed and measured. Alternative estimates of sediment transport or error assessment, if possible. Assessment of the long-term representativity of the data obtained, based on the likely recurrence or frequency of the events recorded.

d) Discussion on the progress obtained relevant to the qualitative and quantitative knowledge of erosion and sediment transport processes.

e) Suggestions for improvement of the measuring Programme.

f) Management-oriented summary (see Conclusions).

Graphs:

- Hyetographs, hydrographs and sedigraphs of the more relevant measured events, comparing stations or seasons.
- Plots of the relationships between measured sediment discharges and water discharges

that were used for the establishment of the sediment rating formulae.

Tables:

- Tables of daily total runoff and sediment transport with totals per month (these tables are for presenting information but the calculations are to be made in the 5-minute step spreadsheets).
- Summary of the main results obtained at the stations, per event, per years and for all the reported period of: precipitation, runoff , runoff coefficient, suspended sediment transport, dissolved sediment transport, mean erosion rate and chemical weathering rate averaged for all the catchment.

Enclosure:

Diskette with copies of the spreadsheet files used for the reported period.

4.4 Interpretation and Presentation of Results

After the process of data acquisition and handling, it would be necessary to perform some interpretation of these data in order to provide a more readable information as well as to highlight the aspects that deserve a special attention but that could be hidden within the longer data report.

4.4.1 Presentation of results for technical purposes

It is difficult to provide guidelines for preparing the technical interpretation of results, because it will depend on the information obtained, the characteristics of the studied area and also on the experience of the team. Nevertheless, this report should cover the following issues:

- A short description of the knowledge of the erosion problems in the area before the implementation of the measuring programme, that justified the selection of this area for measuring.
- An assessment of the new qualitative and quantitative aspects of erosion processes learned during the Programme. Erosion and sediment yield rates for individual events or averaged for the year should be summarized here, together with some information on runoff coefficients and dissolved solids concentrations.
- An estimation of the reliability of the data obtained, with some discussion on the behaviour of sediment concentrations during the events, the similarity or differences among events, the seasonal patterns of erosion and sediment transporting events, and the representativeness of the events that occurred during the measuring period, looking to the long-term rates. The advantages or limitations of the measuring programme should be discussed here.
- Finally, an assessment of the relevance of the erosion and sediment yield rates measured with respect to the problems of land degradation, water quality deterioration and damages to hydraulic structures.

The implementation of an erosion measurement programme in an experimental area requires the involvement of a team of experts. An orientation about the composition and dedication of such a team is presented on the basis of the experience acquired in the three field sites during the implementation of the pilot project.

The instrumentation required will be also summarised and an indication of the instruments` prices will be provided.

The following estimations about the necessary staff, time and equipment are made on the basis of the standard experimental site described in Chapter 3, and for a period of three years. This time is considered fit to the process of selection and installation of the experimental area, including a first year of full functioning and data acquisition, processing and implementation.

To facilitate the understanding, the instrumentation and other equipment aspects of the experimental area will be presented first, followed by the estimation of the required staff and an indication about the field visit programme.

The necessary equipment is composed of:

- the field instrumentation;
- the auxiliary equipment; and
- the laboratory for sample analysis.

Recommendations about the experimental area have been presented and can be summarised as: extension up to 20 km^2, three or more catchments instrumented in the same experimental area, control of land use guaranteed in the mean-long term, easiest accessibility allowed by the experimental objectives, protection against natural hazards and vandalism, channel stability in the reach of measurement.

Field instrumentation, presented in detail in Chapter 3, is composed of:

- Runoff control structure. Flume or weir according the circumstances of bedload transport of the flow.
- Data logger. Two counting channels. Minimum autonomy of one month with a recording rate of 5 minute. Alkaline batteries with life longer than 12 months.
- Water level sensor. An electronic device to convert water level into an electronic impulse. Directly readable by the data logger. Capacitive sensor device is recommended for semi-arid conditions.
- Suspended sediment sampling instrument. Two simultaneous systems recommended: a) a programmable pumping water instrument triggered by the data logger or other water level threshold triggering mechanism, and able to output signals to the data logger to record the exact time of sampling; b) a siphon sampling device, consisting on a series of bottles at different heights, which takes water samples at various water levels as the hydrograph rises. This is to avoid the miss of the higher part of the hydrograph. The bottles are installed in a panel installed in a vertical of the flow.
- Rainfall recording stations. A minimum of one rain recorder per hydrometric station. Tipping bucket mechanism pluviometers connected to data logger and with 0.2 mm resolution, recommended.

The auxiliary equipment is listed in Chapter 3. From all the instruments and materials cited, the portable computer accounts for a good part of the cost. It is necessary to underline its features of reliability, robustness, autonomy and weight. A waterproof bag is an essential accessory as well as cables, plugs or specific interface devices for connection with the data logger and the required software for data transmission to the computer.

The laboratory equipment is also detailed in Chapter 3. To the cost of the listed material it is necessary to add the cost of the room and conventional facilities and services (water supply, electricity, maintenance, etc...) that is usually provided by the implementing agency.

The recommended staff necessary for the three years of implementation including one year of complete operation is composed of:

- Research leader responsible of the project. Experienced researcher in soils and surface hydrology. Provides design, direction and supervision of the project. Part time dedication to the project. 12 man/months.
- Research leader assistant. Experienced researcher in soils and/or surface hydrology. He or she is the executive researcher of the project, full time involvement. To be able to assume leadership if circumstances requires. 36 man/month.
- Two junior researchers. Post doctoral (Ph.D.) or pre-doctoral researchers on soil or hydrology. Responsible for performing the operation of the project under the direct supervision of the research assistant. Installation of facilities, instrumentation, data acquisition, process and interpretation. Operation of installations and maintenance. Laboratory analysis. 2 x 36 man/months
- Auxiliary (non technical) personnel. One field assistant, mainly for maintenance and custody of installations. Advisable with residence in the vicinity of the experimental area. 12 man/month. Secretary staff personnel mainly for document production, and general management assistance. 12 man/months.

The programme of visits is highly conditioned by the weather:

- one or two weekly visits in rainy weather for maintenance of samplers;
- one monthly visit for data recovering; and
- eventual visits during discharge events for direct sampling, maintenance and general operation supervision.

The financing of research initiatives on erosion measurement may arise from diverse sources according to the context of the specific research project. The primary source should be the budget for research at the national level. If a National Erosion Control Programme is set up, as advised, it should provide the adequate mechanisms to channel the required research funds.

International or supra-national organisations may play an important role in some cases. The Commission of the European Communities Research Programme provides substantial funds for research projects on the environment, amongst them erosion measurement projects are included. That funding is restricted to the member countries, but the Commission of the

European Communities (CEC) has other programmes targeted to non-member countries. In this context and particularly aimed to the co-operation with Mediterranean non-member states, the MEDA programme should be underlined because of its importance and potential source of funding projects in diverse fields, among them the environmental co-operation (CEC, 1996).

The United Nations system traditionally provides funding opportunities for applied research projects in the field of earth sciences, agriculture, water resources, environmental protection, etc... There are several UN agencies involved, among them FAO, UNESCO, UNDP and UNEP should be quoted.

CONCLUSIONS

1. THE FINAL PRODUCT: A TOOL FOR DECISION-MAKING

The final product of the mapping and measurement process presented in these Guidelines is composed of:

a) maps presenting the erosion status and erosion processes;

b) measurement results;

c) interpretation of these maps and results; and

d) management proposals for professionals and decision-makers.

In addition, reports on mapping phase, measurement phase, interpretation and proposals will be presented either separately or within a final report including a summary report for decision-makers.

The following points illustrate the approach to the presentation of final documents:

1.1 Presentation of results in a management-oriented manner

The report should contain a summary written in a way that is understandable and useful for decision-makers.

a) The benefits obtained with the mapping and measurement programme should be presented. This will include the list of the new information obtained in it (basic interpretation of mapping results, rainfall, runoff, runoff coefficients, peak discharges, dissolved loads, suspended loads, erosion rates). A comparison with the spatial and temporal resolution of the data obtained through customary schedules by water or soil Authorities should also be discussed.

b) The environmental significance of the information obtained should be presented, combining the information existing before the mapping results and the results of the measuring programme with the more quantitative information obtained during it. The integration with the information obtained during the mapping programme is highly desirable. The fact that this information is the most realistic possible (neither catastrophic nor optimistic) should be highlighted. Although the design of erosion control works or land management strategies is not a direct purpose of the mapping and measurement project, the need for these policies as well as some general recommendations for their implementation should be presented.

c) A generalisation of the provided information should be made. This should include an estimation of the environmental significance of areas with similar problems in other parts of the country, as well as the comparison with other areas where erosion rates are known. A comparison of the quality of data provided by the Programme with other data should also be made. The information on sediment transport rates and processes is to be used together with the mapping information to identify and assess the sediment sources within the catchments. Land management strategies for erosion control must be directed to sediment sources and pathways to improve the effectiveness/cost ratio.

d) Finally, some recommendations on the future application of the results of the mapping and measurement programme should be made. These could include aspects like changing the scale of the study either to more detailed scales (plot studies) or to wider ones (bigger catchments); checking the quality of other data on erosion rates; implementing similar programmes in other areas with erosion problems; or using the instrumented catchments to check the effectiveness of erosion control works or land management strategies.

From the point of view of the management aspects, the implementation of the erosion mapping and measurement programme as has been described implies the existence of several prerequisites that include:

- A **co-ordinated** and integrated **management** effort comprising various Government/authorities levels: the responsible and interested national ministries, as well as lower-level and local authorities. Relevant sectorial decisions have to be prepared, discussed and approved, securing harmonisation with other sectorial activities, adequate and timely information, financial and other logistical elements defined, and implementing agency/institution nominated;

- **The implementing agency to be nominate**: the necessary professional and organisational level achieved, equipment provided, training performed (if necessary);
- **The erosion control programme for the area** to be formulated and approved, preferably as a part of the National Erosion Control Programme, and in harmony with the priorities established at the national level;
- Institutional, logistical, managerial, legal and **other problems**, if any: identified in time and resolved with respect to the mapping and measurement area, field visits, equipment to be installed /maintained;
- Timely and adequate **training of staff**: to be organised at the level of implementing institution, **information and general training** at other levels, if necessary and appropriate;
- **Management elements to be included in the programme**: harmonisation and correlation of the field measurements with the mapping exercise; interpretation of the results achieved; formulation of proposals for mitigation/control or prevention measures to be implemented within the erosion control programme; interpretation of the results and proposed measures at ICAM level in order to achieve firstly intra-sectorial integration, and secondly multi-sectorial integration;
- **Implementation team**: details of the composition, organisation of work and involvement of the implementation team are contained in the respective chapters of the Part I and Part II.

2. RECOMMENDATIONS AND PROPOSED ACTIONS FOR MANAGERS

Erosion is primarily the result of misuse of land, over-exploitation of natural resources, intensification of agriculture, anarchic development of tourism, communication, urbanization, etc. Mediterranean coastal areas have been subject to tremendous development for several decades to the detriment of interior regions which, on the contrary, have seen the population and human activities diminish. Often integrated development master plans are nonexistent, non integrated, incomplete or obsolete because they have been overtaken by the actual development of the region. Decision makers often lack the political will to stop or at least brake this wealth-generating development.

In order to prevent future degradation due to uncontrolled erosion and to mitigate existing erosion problems, as a starting point, every Government should:

- make an inventory of land resources (climate, soil, water, biota), gathering fragmented data and filling in gaps by survey and remote sensing combined with geographic information systems;
- assess potentials and constraints of local development projects including all different sub-sectors that coastal areas of the Mediterranean are likely to offer: farming, industry, communication, urbanization, tourist facilities (sport grounds, hotels, camps, aquatic sports, etc.) and conservation practices, and identify options to raise land productivity and decrease risks while reducing degradation;
- study reasons behind poor land use, including land tenure problems, pricing of agricultural produces and inputs, subsidies, taxes, laws and social customs;
- plan phased changes to develop land management practices and to encourage individual operators and farmers to adopt sustainable forms of land use and development.

This will help identify strategies for an anti-erosive, land conservation programme; it will also help national and local governments avoid schemes which treat symptoms rather than the causes and encourage the awareness and the participation of all land users. Past land conservation and rehabilitation projects have often relied heavily on the construction of physical infrastructures. Such practices are expensive per unit area conserved and/or rehabilitated and maintenance is a problem after support staff and equipment are withdrawn. Also, it is difficult to apply these strategies widely or quickly enough to overcome erosion problems of a large scale. Consequently, the ideal erosion control programme is one in which land users plan and implement solutions. To this end, governments should create greater awareness of erosion control and land improvement potentials while addressing land degradation issues. This implies the use of the media and training of technical staff to assist land users in this new approach.

2.1 Developing strategies

Each Mediterranean country must develop policies and strategies relevant to local circumstances. Under the guidance of a high level advisory commission composed of erosion mitigation specialists, land use planners, as well as of responsible authorities and political representatives, one clearly defined ministry department should have the overall responsibility and authority to:

- back up services to land users by rationalizing and strengthening institutions plus appropriate training, research and legislation to support the conservation effort;
- appraise the conservation components of regional development programmes, with political, social and economic information used to formulate a policy and long-term anti-erosion and conservation strategies;
- develop detailed programmes, about 3 to 5-year rolling plans which must be reviewed and updated annually; and
- promote local programmes according to the present needs.

2.2 Catalyzing Regional Programmes

Regional programmes give each country the chance to benefit from other countries' successes in anti-erosion and land conservation efforts, and in particular:

- Overall training needs should be assessed so that appropriate multidisciplinary courses can be developed in key regional universities and specialized institutes.
- As research is expensive, efforts can often be pooled where conditions are similar and priorities identified.
- Research findings can be spread through simple networks and newsletters.

2.3 Coordinating International Actions

In order to control or prevent erosion, and maintain permanent installations, many countries need the support of technical agencies.

- Governments should commit themselves to the long-term policies, programmes and financial requirements that can bring about sustainable forms of land use.
- Technical organizations should help formulate overall programmes. By doing so they can identify where and how their inputs can best be used and they can fit contributions together in an overall national action plan.

ANNEX I:
ROLE OF EROSION ASSESSMENT PROGRAMMES WITHIN THE FRAMEWORK OF INTEGRATED COASTAL ARES MANAGEMENT

1.1 ICAM - A Major Tool of Sustainable Development and Environment Protection of Coastal Areas

Coastal area could be defined as an organic whole consisting of the littoral land, coastal strip, shoreline, and the adjacent sea. These areas are characterized by intensive physical, biological, social, cultural and economic processes, and their interactions. Changes in any segment of the system often have impacts in other, sometimes remote segments.

Due to their specific character, most valuable resources and diversity, the coastal areas offer good base and conditions for economic growth and socio-cultural development, so that they have been attracting population during the entire history of the mankind. In the recent past, those conditions led to a strong, often uncontrolled development, high increase of coastal population, and unsustainable use and depletion of many precious resources. The consequence was a dramatic deterioration of the state of the environment and the quality of living. In many coastal areas, the increasing pressures on the eco-systems and high pollution resulted in irreversible disruption of the most fragile eco-systems.

The ever growing concern related to ultimate consequences of such trends resulted in the formulation of the concept of sustainable development in the 1980s, and most recently, in the adoption of the UNCED Rio 1992 documents. One of those, the "Agenda 21" establishes the principles, and defines goals and activities to be implemented by the states towards achieving sustainable development. Chapter 17 of the "Agenda 21" is related to coastal areas and at the moment represents, perhaps, the most important international document related to ICAM.

There are several usually quoted definitions of sustainable development. Here, the original Brundtland definition will be presented as recently amended by the MAP - Blue Plan (UNEP/MAP - Blue Plan, 1995):

"The sustainable development is a development in respect of the environment, technically appropriate, economically viable and socially acceptable to meet the needs of the present generations, without compromising the possibility of future generations satisfying theirs."

With reference to coastal areas, the same concern was reflected still in the early 1970s in the development of the concept and first instruments of ICAM. Initiated in the USA, ICAM was gradually development and implemented in many coastal states and areas throughout the world. Within the MAP, the PAP and the Blue Plan have been implementing ICAM related activities since the early 1980s. FAO is also involved in a number of ICAM activities and projects.

ICAM is a continuous, pro-active, and adaptive process of resource management for sustainable development in coastal areas. ICAM focuses on:

- strengthening of sectorial management and their integration;
- preserving and protecting the productivity and bio-diversity of coastal eco-systems; and
- promoting rational development and sustainable use of coastal resources.

Based on the integration of multi-level and multi-sectorial activities and decisions, ICAM is not a substitute for sectorial planning, but it integrates the sectorial plans in order to achieve comprehensive goals, such as, among others:

- define the sustainable mode and level of resource use;
- renew or rehabilitate damaged resources;
- ensure that the rate of loss of resources does not exceed the rate of replenishment;
- reduce risks to vulnerable resources;
- respect natural dynamic processes, preventing adverse interferences; and
- protect traditional resource uses.

Sectoral inputs	Stages	Phases	Activities	Outputs	Political decisions
Triggers: past decisions, new decisions, external influences	**INITIATION**	*INITIATION OF ICAM*	Analysis of prerequisites for ICAM. Tentative boundaries of the area. Preparation of the proposal for initiation of ICAM.	Proposal for the preparatory phase of ICAM	To start ICAM
Sectoral Problem identification	**PLANNING**	*PREPARATORY ACTIVITIES*	Definition of coastal area. Identification of sectoral and cross sectoral problems. Proposal for general goals and objectives. Preparation of development environment, outlooks and tentative strategy. Identification of information gaps. Definition of legal, financial and institutional requirements for ICAM. Proposal for integrated Coastal Master Plan preparation procedure.	Coastal Profile ICAM programme	To establish ICAM as a continuous and long term process
Sectoral analysis and forecasting		*ANALYSIS AND FORECASTING*	Issue-oriented new surveys (generation of missing primary data). Analysis of natural and socio economic systems. Forecasting of future demand. Generation of cross sectoral scenaria and selection of preferred scenario.	Alternative scenaria	
Definition of sectoral goals and strategies		*DEFINITION OF GOALS AND STRATEGIES*	Proposal for sectoral and cross sectoral goals and objectives. Preparation of alternative strategies including legal requirements, financial implications and institutional arrangements. Evaluation and selection of strategy.	Management strategy	Approval of goals objectives and strategies
Sectoral plans		*INTEGRATION OF DETAILED PLANS*	Allocation of land and sea uses. Proposal for implementation procedures (legal, institutional, financial) and relevant instruments (EIA, CBA, etc). Definition of implementation stages. Draft Integrated Coastal Master Plan presented to relevant body for approval.	Integrated Coastal Master Plan	Adoption of Integrated Coastal Master Plan and relevant policies
Sectoral plans and policies	**IMPLEMENTATION**	*IMPLEMENTATION OF PLANS*	Phasing of ICAM proposals and policies. Application of economic, regulatory, and environmental evaluation instruments in development control. Adaptation of institutions to ICAM.	EIA CBA	Approval of implementation instruments used in the development control process
Sectoral monitoring		*MONITORING AND EVALUATION*	Redefinition of cross sectoral problems. Identification of inadequacy of instruments.	Evaluation study	Update of ICAM process

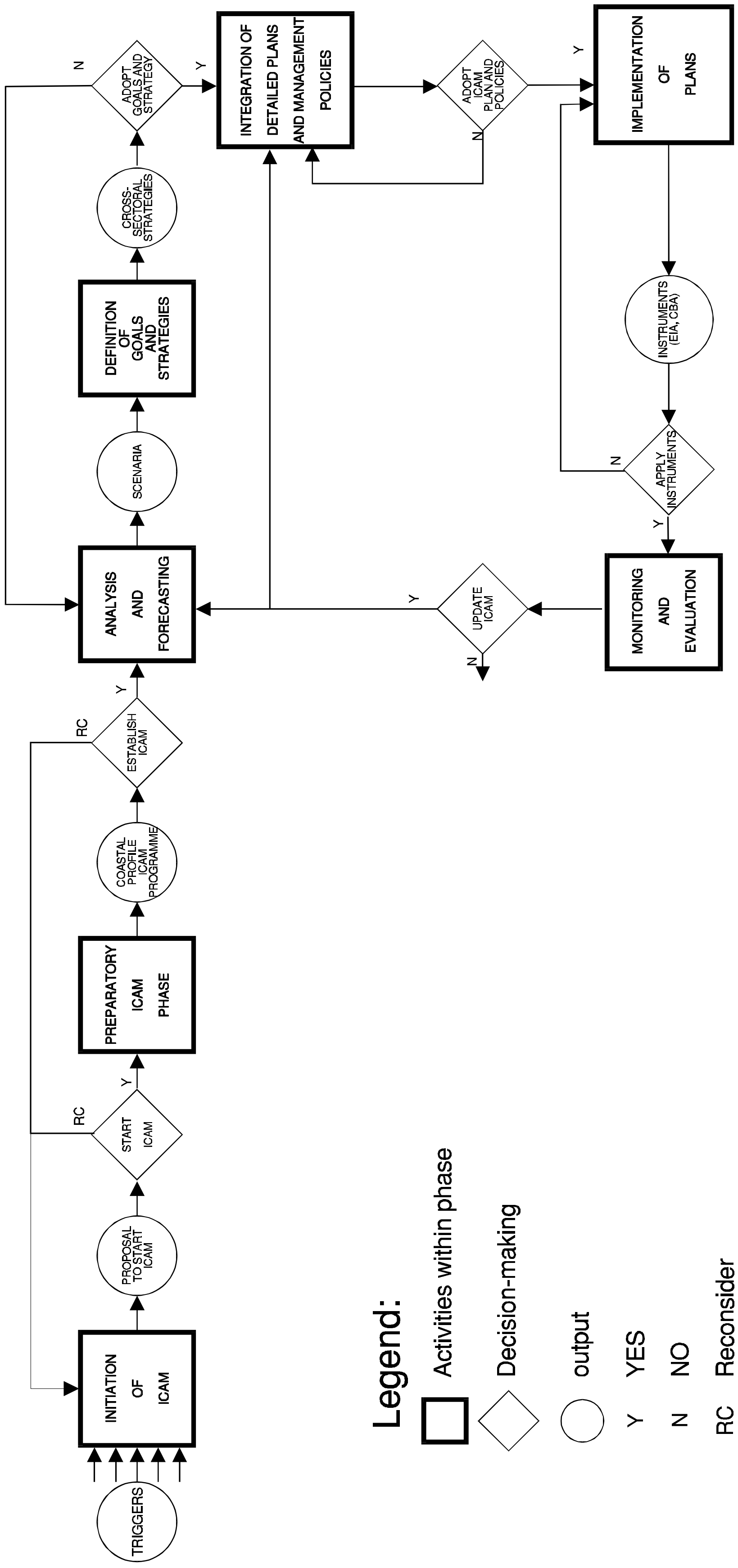


Figure A-1. Flowchart for ICAM process (source: UNEP, 1995)

ICAM is a long-term and feed-back process, basically composed of three stages:

- initiation;
- planning; and
- implementation.

The **planning stage** contains the following phases:

- preparatory activities;
- analysis and forecasting;
- definition of goals and strategies; and integration of detailed plans.

The **implementation stage** contains:

- implementation of plans;
- monitoring; and
- feed back.

Each ICAM phase/stage is defined by a sequence of activities, outputs, decisions, and feed-back. The stages and phases of ICAM are presented in Table A-1 and Figure A-1, according to UNEP/PAP.

1.2 Mapping and Measurement of Erosion Processes - Role in ICAM

Mapping and measurements of erosion phenomena are the basis for assessment and evaluation of the causes, present state, intensity, and trends of erosion. The impacts of erosion on coastal resources, economic activities, agriculture in particular, environment, and pollution, as well as their social consequences are of primary importance for many Mediterranean coastal areas. Therefore, erosion assessment makes part of the basic diagnosis exercise for the ICAM process. Maps of erosion-affected areas, prepared on the basis of the common consolidated methodology, represent in many cases an indispensable input for the mapping phase of ICAM, and particularly for GIS, if applied. Furthermore, ICAM programmes usually encompass large coastal areas and are, in many cases, based on regional or multi-national cooperation. Consequently, the application of the common consolidated methodology has to be considered not only as a benefit, but primarily as a must. Even in the cases when in the initial phase of ICAM the analysis of available information indicates the absence of severe erosion-generated impacts in the relevant coastal area, the identification and mapping of potential erosion-effected sites is indispensable. Again, in cases of severe erosion processes, the mapping using the common consolidated methodology is needed for the same reasons (cooperation, comparative evaluation, inclusion in GIS or other overlaying mapping techniques). The mapping procedure can be completed in a reasonably short time, avoiding thus to affect the general time-table of the ICAM programme or project.

Both mapping and measurements need adequate interpretation for ICAM, including recommendations of erosion control measures to be considered as input in the ICAM planning phase. With respect to ICAM, the important elements to be interpreted are most frequently related to the following impacts:

- **primary impacts**: land degradation, loss of productive soil, sediment transport, landscape degradation;
- **secondary impacts**: loss of productivity, decline of relevant activities (Mediterranean agriculture, cattle raising), deposition of eroded material (water ways, dams), change in sediment flux and natural balance along the shoreline, pollution of fresh waters and the adjacent sea; and
- **tertiary impacts**: change in rainfall pattern, endangered bio-diversity, social impacts (poverty, migrations), economic impacts (life time and economic value of dams, impacts on tourism if beaches are eroded or polluted).

The interpretation of the above and/or other, if any, existing or potential impacts on sustainable use of resources and coastal management pattern have to be carefully considered and interpreted during the analysis of the results achieved by erosion mapping and measurements.

With reference to ICAM phases and stages presented in the point 1.1, the role and place of erosion control activities is presented in the Table A-2.

ICAM		ECA
Stage	Phase	
Initiation	-	Analysis of prerequisites and needs for ECA.
Planning	Preparatory	Problem identification, evaluation of data and information, of human and institutional capacities. Rapid assessment of affected or potentially affected areas. Training for mapping using common methodology. Mapping. Measurements initiated, if needed.
	Analysis and forecasts	Mapping completed. Analysis of information including maps. Forecast of erosion consequences. Development of alternative erosion control scenarios. Selection of preferable scenario. Study of legal and/or institutional improvements, if needed.
	Goals and strategies	Definition of erosion control goals, and development of the First Best Strategy. Development of management structures. Measurements completed, updating of FBS, if needed. Development of erosion control programme.
	Integration of detailed plans	Integration of erosion control programmes in ICAM plan. Measures for harmonized, integrated implementation.
Implementation	Implementation	Implementation of erosion control plans within ICAM plan.
	Monitoring	Field monitoring and measurements, if needed. Redefinition of erosion control plan, if needed. Feed-back and updating of erosion control activities.

Table A-2: Role of Erosion Control Activities (ECA) in ICAM (source:UNEP, 1995)

ANNEX II:
GLOSSARY OF TERMS

Cableway *(F.: Station téléphérique; S.: Teleférico de aforro)*. Cable stretched above and across a stream, from which a current meter or other measuring or sampling device is suspended, and moved from one bank to the other, at predetermined depths below the water surface. The instrument may be operated from the bank or from a cable carrying personnel.

Calibration *syn* rating *(F.: Réglage, calage; S.: Calibración)*. Experimental determination of the relationship between the quantity to be measured and the indication of the instrument, device or process which measures it.

Catchment or watershed *(F.: Bassin versant; S.: Cuenca)*. That area determined by topographic features within which rainfall will contribute to runoff at a particular point under consideration.

Data logger *(F.: Appareil de télémesure; S.: Registrador electrónìco)*. Electronic instrument designed to read and store information, such as rainfall and water level. The memory of the instrument allows a one-month autonomy with a recording rate of 5 minute-step. The instrument is directly interrogable by a portable computer.

Drainage network *(F.: Réseau de drainage; S.: Red de drenaje)*. Arrangement of natural or man-made drainage channels within a catchment.

Ephemeral stream *(F.: Cours d'eau sporadique; S.: Curso de agua intermitente)*. Stream becoming dry during the dry season or in particularly dry years.

Erodibility *(F.: Erodibilité; S.: Erodibilidad).* Susceptibility to erosion, erosion proneness. Sands are generally more erodible than silts, and silts more than clays; no fully satisfactory soil erodibility assessment method has yet been found. Soil erodibility might change according to the soils' physical conditions (Soil wetness, frost, recent tillage or compaction). Angular soil particles are more interlocking than rounded particles; soil colloids cement particles together; compaction increases total surface contact among particles. (Hewlett, 1982)

Erodibility Map, from the current elaborated Mediterranean common mapping methodology, expresses the same practical concept by crossing the soil's qualitative erodibility with the slope factor to assess the overall land erosion susceptibility.

Erosion *(F.: Erosion; S.: Erosión):* The wearing away of the land by running water,rainfall, wind, ice or other external agents, including such processes as detachment, entrainment, suspension, transportation and mass earth movement.(SCS-New South Wales,1986)

Erosion Risk *(F.: Erosion potentielle; S.: Riesgo de erosión):* Probability rate for an erosion process to start and develop as a result of changes of one or several erosion inducing or controlling factors. While climate, soil and topography are fairly stable, vegetation cover, land use and management are more liable to modifications. The concept of risk is equivalent to that of POTENTIAL erosion. (Giordano, 1991).

Erosion Status *(F.: Etat érosif; S.: Estado erosivo):* Actual and/or Potential Erosion assessment as related to the local environmental features such as topography, geology and soils, vegetation cover and land use. Rainfall and other climatic features are not taken into account**.**

Erosion Trend *(F.: Tendance évolutive de l'érosion; S.: Tendencia de erosión)*: The predictable tendency of an erosion process to develop or to stabilize in terms of nature, intensity and/or area expansion.

Erosivity *(F.: Erosivité; S.: Erosividad):* Potential ability of physical dynamic agents such as water, wind or ice to cause erosion. Falling rain is more erosive than water moving over the surface of the ground. Drop size, falling velocity and intensity are rain features related among themselves which determine rainfall erosivity. (Hewlett, 1982).

Flume *(F.: Canal d'essai; S.: Canaleta)*. Man-made channel with clearly specified shape and dimensions which may be used for the measurement of discharge.

Gully or Channel Erosion *(F.: Erosion concentrée, Ravinement; S.: Erosión en cárcavas).* The removal of soil by the formation of relatively large channels or gullies cut into the soil by concentrated surface runoff. In contrast to rills, gullies are too deep to be obliterated by ordinary tillage practices. (U.S. Soil Conservation Service, 1951)

Landslide *(F.: Glissement de terrain; S.: Deslizamiento de terreno*): A slope Mass Earth movement where a soil or substrata mass slides over a contact surface called sliding surface.

Lithofacies *(F.: Lithofaciès; S.: Litofácies)*: A term used to describe the physical mechanic and organic features of local soil and subsoil conditions.

Load *(F.: Charge solide; S.: Carga sólida)*. The weight of dry solids being transported in any mode by the action of gravity, wind or water.

Load (bed) *(F.: Charriage de fond; S.: Carga de fondo)*. Coarse grained sediments transported don the bed of a stream.

Load (dissolved) *(F.: Charge soluble; S.: Carga soluble)*. Sediments transported in solution.

Load (saltation) *(F.: Transport solide par saltation; S.: Transporte por saltación)*. Sediments whose mode of transport fluctuates between suspended and bed.

Load (suspended) *(F.: Sédiments en suspension; S.: Sedimentos en suspensión)*. The total sediments moving in water -combination of wash load and bed load.

Load (wash) *(F.: Transport en suspension; S.: Transporte en suspensión)*. Fine grained sediments moving in water entirely in suspension.

Managed Area *(F.: Milieux exploités; S.: Medios intervenidos)*: Area of land where one or several human interventions take place which are directly related to the land, making use of its resources, or having an impact upon it.

Mass Earth Movements *(F.: Mouvements de masse; S.: Movimientos en masa):* Erosion where main causative agents are water-logging and gravity. Heavy and/or prolonged rains are usually the triggering factors. Landslides, mudflows, rock falls and soil creep, are mass movements.

Morphology (of a basin) *(F.: Morphologie; S.: Morfología)*. Characteristics of a drainage basin, e.g. basin area, longitudinal stream profile, topography, etc.

Mudflow *(F.: Lave torrentielle; S.: Lava torrencial):* Muddy flow composed of water and a very high concentration of sediments and solid weathering debris and which has been generally originated by mass earth movements such as landslides in the upstream sections of the catchment.

Perennial stream *(F.: Cours d'eau pérenne; S.: Curso de agua permanente)*. Stream which flows continuously all through the year.

Rainfall simulator *(F.: Simulateur de pluie; S.: Simulador de lluvia)*. Device to apply water in a form and at a rate comparable with natural rainfall.

Reach *(F.: Tronçon; S.: Tramo)*. Long straight stretch of a river in which the hydraulic elements remain rather uniform.

Recurrence (interval) *(F.: Récurrence, intervalle de ~; S.: Recurrencia, intervalo de ~)*. The average time interval between actual occurrences of a hydrological event of a given or greater magnitude.

Rill Erosion *(F.: Erosion en rigoles; S.: Erosión en regueros):* Removal of soil by the cutting of numerous small, but conspicuous water channels or tiny rivulets by concentrated surface runoff. The marks of rill erosion may be obliterated by ordinary tillage practices. (U.S. Soil Conservation Service, 1951)

Sediment concentration *(F.: Concentration en sédiments; S.: Concentración de sedimentos)*. Quantity of sediment carried in a unit volume of water. The preferred symbol is Cs. With units of kg/m^3.

Sediment delivery ratio *(F.: Pourcentage de sédiments transportés; S.: Porcentaje de acarreo)*. Percentage between the sediment transported by a river and the total quantity of erosion material in movement, both relative to the drainage area at one particular section.

Sediment (solid) discharge *(F.: Débit solide; S.: Acarreo sólido)*. The quantity of sediment, measured in dry weight per unit time, transported through a channel cross-section. (It is obtained by multiplying the sediment concentration by the stream discharge).

Sediment (siltation) *(F.: Sédimentation; S.: Sedimentación)*. Deposition by water of sediment. Technically the term siltation refers to the deposition of silt particles, but it is more commonly used to refer to the deposition of sediment.

Sheet Erosion *(F.: Erosion en nappe/Laminaire; S.: Erosión laminar):* The removal of a fairly uniform layer of soil from the land surface by runoff or wind. (Soil Conservation Society of America, 1970)

Stable Area *(F.: Milieux stables; S.: Medios estables)*: Area of land with no evidence of any active erosion processes, because of the predominant stabilizing effect of one or several landscape components thus generating a state of morphodynamic equilibrium.

Stilling pond *(F.: Bassin de décantation ou de tranquillisation; S.: Tanque de decantación)*. Pond connected with a stream in such a way as to permit the measurement of the sedimentation in relatively still water.

Soil Crusting *(F.: Encroûtement; S.: Sellado del suelo):* Process of compaction and cementation of fine soil surface particles removed and accumulated by splash and sheet erosion processes which can lead to a complete sealing of soils pores.

Splash/Raindrop Erosion *(F.: Erosion pluviale/aréolaire; S.: Erosión pluvial):* The spattering of soil particles caused by the impact of raindrops on the soil. The loosened particles may or may not be subsequently removed by runoff; splash erosion is an important component of sheet erosion.

Terracetting *(F.: "Pieds-de-vaches"; S.: Pisoteo)*: The characteristic pattern formed by numerous gently inclined steps or ledges traversing a hill slope. It is apparently caused by the combined action of soil creep and the tread and trampling of animals

Thalweg *(F.: Thalweg; S.: Talweg/Vahuada):* A term frequently used to designate the longitudinal profile of a river, i.e. from source to mouth following the line of the lowest points of a valley.

Torrential *(F.: Torrentiel; S.: Torrencial)*. Flow in a watercourse having a steep slope with great velocity and turbulence.

Trap efficiency *(F.: Pourcentage de sédiments capturés; S.: Porcentaje de sedimentos retenidos)*. Ability of a reservoir to trap and retain sediment, expressed as a percent of sediment yield (incoming sediment) which is retained in the reservoir.

Turbidity *(F.: Turbidité; S.: Turbidez)*. Presence of fine visible material in suspension in a liquid which is not of sufficient size to be seen as individual particles but which prevents the passage of light through the liquid.

Unstable Area *(F.: Milieux instables; S.: Medios inestables)*: Area of land where one or several active erosion processes occur.

Vegetation Cover *(F.: Couvert végétal; S.: Cobertura vegetal):* Portion of soil which is covered by the plant canopy.

Water Divide Line *(F.: Ligne de partage des eaux; S.: Divisoria de aguas):* Dividing ridge between two catchments.

Waterlogging *(F.: Engorgement; S.: Anegamiento)*. Condition of land when the water table stands at or near the land surface and may be detrimental to plant growth.

Weir *(F.: Seuil; S.: Vertedero)*. Overflow structure which may be used for controlling upstream water level or for measuring discharge or for both.

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