MODIPE: Model and software for the design of water harvesting systems in restoration schemes

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Abstract

For the design of water harvesting structures ensuring a successful restoration (afforestation) of arid lands (microcatchments, ridging, terracing, etc.) we have developed this new model and software, called MODIPE. The program estimates the infiltration (i. e. available water prior to a soil water balance) in a slope after a storm, a series of storms or even on an annual basis. It also calculates the minimum reservoir capacity of the micropond if all of the surface runoff is to be retained in the collecting area (concept of endorheic microcatchments). MODIPE is a particular and practical solution of the general hydrologic model developed by the author that works with the curve number method. In a brief way we give some ideas and hypotheses fundamental to this model before building up an example to show the potential usefulness of this software.

Key words: water harvesting, hydrologic model, curve number method, restoration, reforestation of arid zones, systematized unit, micropond, endorheic microcatchment, simulation, informatization

1. Introduction

Used since ancient times, water harvesting is a technique still relevant today in the struggle against desertification of arid and semiarid lands. In the sense that it is used here, it encompasses the management and tapping of surface runoff through some alteration in the ground surface of a slope in order to collect enough water to meet the requirements of seedlings during their establishment and first stages of growth. An appropriately spaced distribution of microponds, microcatchments, microbasins or mini-dams increases infiltration, reduces surface runoff and checks the erosion hazard.

Although the usefulness of this traditional technique has not been questioned, no hydrological model applicable to restoration schemes appears to have been developed to date. It is to be hoped that this work will go some way towards filling this gap.

MODIPE is a software program to help reach the right diagnosis in many desertification processes and to assist in the decision-making process prior to the implementation of rehabilitation plans of degraded slopes. Thus, this software program:

a) characterizes slope microclimates;
b) offers a better understanding of the desertification process in arid lands;
c) simulates the behaviour of any systematized unit;
d) evaluates the effect on surface runoff of different procedures followed in the preparation of the ground surface for reforestation;
e) enables the user to design mini-dams (reservoirs) which improve infiltration and provide suitable microsites for the survival of seedlings under arid and semiarid conditions.

2. How does the program operate?

MODIPE works out available water (i.e. infiltration) at a specific spot on the slope after a storm or a series of storms. It can also operate on an annual basis or even with longer periods of time.

The topographic hydrological characteristics of the slope as well as the rainfall should be defined. From these data the program quantifies surface runoff generated by these storms and estimates the amount of water present at a specific spot on the slope. This value represents the available water at that spot.

The program contemplates the possibility of operating with systematized slopes and in such cases it differentiates between those areas receiving runoff (collecting areas), and those providing runoff (contributing areas).

As the final output, the amount of available water (l/m^2) at a point on the slope is obtained (regardless of whether there is an excess or a deficit in the accumulation and infiltration of water by intrinsic and/or extrinsic reasons).

The output is displayed on the screen and a print-out is obtained by pressing the key [Print Screen]. Another option is to retrieve such images for later interpretation or edition by means of one of the widely used packages.

MODIPE (version 1.1) is a user friendly program to be run on any compatible personal computer.

The model requires as input data:

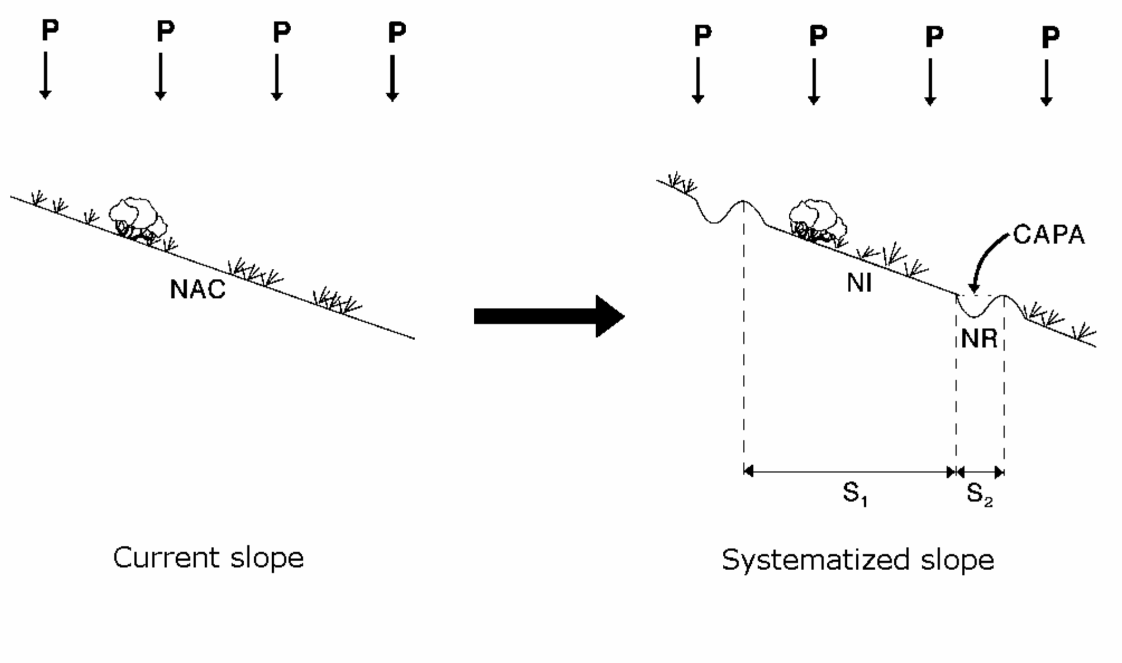
- the curve number on the current slope (in condition 2), *NAC*
- contributing area, S_1 (m^2)
- collecting area, S_2 (m^2)
- curve number of the contributing area (in condition 2), *NI*
- curve number of the collecting area (in condition 2), *NR*
- reservoir capacity of the collecting area, *CAPA* (l)
- rainfall data and previous ground moisture data

In this respect there are three possibilities:

-a- For a single storm
  - quantity of rainfall, *P* (mm)
  - antecedent moisture condition, *J* [1, 2 or 3]

-b- For a series of storms
  - quantity of rainfall for each storm, *P(I)* (mm)
  - antecedent moisture conditions, *J(I)*

-c- For a one-year period
  - monthly precipitation, *PM(I)* (mm)
  - maximum daily precipitation in the month, *MM(I)* (mm)
  - number of days with appreciable[1] precipitation, *DM(I)*



Input data for MODIPÉ

[1] [appreciable means more or equal to 0.1 mm]

The output will be the available water for the slope:

- without primary systematization: *ANTES* and
- with systematization:
    a) on the contributing area: *PIMP*
    b) on the collecting area: *DESP*
    c) on the systematized unit: *PROM*

In addition, this program calculates the minimum reservoir capacity (*CAPAL*) of the micropond if all of the runoff is to be retained; in other words, if the systematized unit is to behave as an endorheic microcatchment.

Some additional results of interest should be mentioned:

- the curve numbers and their runoff thresholds (for the three moisture conditions contemplated in the curve number method)
    a) on the current slope: *NAC(J)* ↔ *PAC(J)*
    b) on the contributing area: *NI(J)* ↔ *P1(J)*
    c) on the collecting area: *NR(J)* ↔ *PR(J)*
    d) on the systematized unit: *NEQ(J)* ↔ *P2(J)*
- recommended minimum reservoir capacity of the micropond (only when $NI < NR$): *CAPMIN*

3. Basis of the model

We will briefly touch upon some ideas and hypotheses fundamental to this model. For further details the reader is referred to items listed in the bibliography.

- A -

The equation used in the calculation of the infiltration at one specific spot (i. e. the available water of this spot previous to a soil water balance) is:

$$H = I = P - I_t - E + E_{s1} - E_{s2}$$

where H = available water; I = volume of infiltrated water; P = precipitation; I_t = interception; E = evaporation from ground surface; E_{s1} = water arriving through surface runoff and E_{s2} = water escaping through surface runoff.

In the case of degraded lands, interception and direct evaporation can be disregarded in a first approach, and hence:

$$H = I = P + E_{s1} - E_{s2}$$

- B -

In a primary systematization the slope is divided into a number of small units. To this effect the terrain is modified by means of ridges, furrows, mini-dams, terracing, microponds. This way the slope is divided into sections. Each section is a systematized unit where, if possible, all runoff should be retained at the lower part of the unit. Such an area where the surface runoff collects is known as the collecting area. The area providing the runoff water is known as contributing area. Both make up the systematized unit. [See appendix I.]

Anticipating extraordinarily heavy rains, the slope should be provided with a drainage network capable of draining surplus water; this artificial network has been termed secondary systematization and acts as a safety outlet for the designed primary systematization.

- C -

a) For the evaluation of the available water on the slope prior to the systematization, the following equation is used:

$$ANTES = P - \Delta E_s$$

where ΔE_s is surface runoff (rainfall excess) generated by the storm (P) on the original slope.

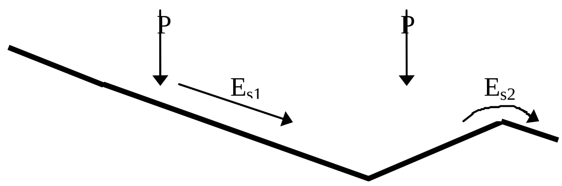
A distinction is drawn between rainfalls ***fully*** or ***partly available*** to the slope, depending on the value of ΔE_s.

b) The equations estimating available water on the systematized slope are:

$$DESP = P + E_{s1} - E_{s2}$$

$$PIMP = P - E_{s1}$$

$$PROM = \frac{S_1 \cdot PIMP + S_2 \cdot DESP}{S_1 + S_2}$$



where: P, precipitation analyzed
$DESP$, available water on the collecting area
$PIMP$, available water on the contributing area
$PROM$, average available water on the slope
E_{s1}, rainfall excess or surface runoff reaching the collecting area
E_{s2}, surface runoff escaping the systematized unit
S_1, surface of the contributing area
S_2, surface of the collecting area.

c) Showers can be classified into four different groups according to the effect they may have on the systematized slope: ***light, adequate, heavy*** and ***harmful.***

1} ***Light:*** below the minimum precipitation ($P1$) necessary to generate runoff on the contributing area

If $P < P1 \Rightarrow E_{s1} = E_{s2} = 0$ mm
$PROM = DESP = PIMP = P$

2} ***Adequate***: when in between the minimum precipitation and the limit ($P2$) before overflowing the systematized unit

If $P1 < P \leq P2 \Rightarrow E_{s1} > 0$ mm and $E_{s2} = 0$ mm
$PIMP < P$ and $DESP > P$ and $PROM = P$

3} ***Heavy***: when ranging between the limit precipitation ($P2$) and the maximum precipitation ($P3$); the secondary systematization is still capable of draining water off through the network.

If $P2 < P \leq P3 \Rightarrow E_{s1} > 0$ mm and $E_{s2} > 0$ mm
$PIMP < P$ and $DESP \leftarrow ? \rightarrow P$ and $PROM < P$

4} ***Harmful***: when it is over and above the draining capacity of the secondary systematization ($P3$); the primary systematization work is under threat of crumbling, rainwater flows uncontrolably and erosion is aggravated.

If $P > P3 \Rightarrow E_{s1} > 0$ mm and $E_{s2} > 0$ mm
$PIMP < P$ and $DESP \leftarrow ? \rightarrow P$ and $PROM < P$

d) Whenever *ANTES* < *PROM* it is advisible to use systematized units for a good water balance on the slope.

4. Exemplification through a case study in El Cerrato (Palencia, Spain)

Let's consider the case of a degraded slope whose curve number in antecedent moisture condition two is 89 (e.g. very poor grassland on a D soil type).

The systematization consists of a series of microcatchments; their contributing area is 9 m^2 and their collecting area 1 m^2 with a reservoir capacity of 200 l, the mini-dikes are 200 mm in height.

The preparation of the ground is limited and restricted to the collecting area. Hence, the curve number of the contributing area in moisture condition two is equal to that of the actual slope [89]. After the work performed on the collecting area, the value of the curve number is 86 (equivalent to that of the same type of poor grassland but on a different type of soil [C], somewhat improved by the loosening up of the soil).

With MODIPE the hydrological behaviour of a slope ecosystem like the one just described can be simulated and then the efficiency of the rehabilitation intended can be assessed.

According to the program's output [see appendix II], we are dealing with a fairly degraded ecosystem with a low capacity for collecting water due to the high curve numbers. This is what the runoff thresholds show: just 6 mm rainfall under average moisture conditions on the slope is enough to generate runoff. When raining on a wet soil (antecedent moisture condition 3), the threshold drops to 3 mm. On very dry soil (moisture condition 1) surface runoff is produced after storms over 15 mm. Under these circumstances dry conditions prevail on the soil even though the average rainfall in the area could lead us to expect otherwise. This situation could be especially serious in climates with torrential rains, few downpours but very heavy and aggressive. Wasting these water resources and the subsequent erosion it entails could bring about an irreversible process of desertification.

As the area is systematized, the hydrological behaviour of the slope changes appreciably. There is a rise in runoff thresholds. The new values in the systematized unit are: 66 mm on a dry soil, 44 mm under average conditions and 32 mm on a wet soil. As a result, that all-important resource, water, will be better used throughout the ecosystem. Chances of a better plant cover are significantly improved, above all in the areas where the water is stored, that is, in the collecting areas. Harvesting water originated in contributing areas can create microsites with levels of available water much higher than those a reading of rain gauge measurements might lead us to expect.

After a 50 l/m^2 storm on a dry soil (antecedent moisture condition 1): on the actual slope this storm would generate an important surface runoff and the final available water value would be low especially when compared with the precipitation fallen (38.8 mm against 50 l/m^2). Conversely, after systematization, the whole volume of water fallen is retained (50 l/m^2). Since the contributing area shows the same curve number as the current (unaltered) terrain, the storm generates runoff. However, the preparatory work carried out on the collecting area results in the retention and storage of that runoff. According to MODIPE, a micropond with a capacity for 107.3 l will be enough to stop runoff from escaping each systematized unit. The planned micropond (200 l in capacity) amply meets the requirement. Thus, average available water in the ecosystem matches the precipitation fallen even though it may have been unevenly distributed. On the contributing area only 38.8 mm remain (as in the current slope) while the collecting area retains and stores runoff providing 150.7 l/m^2 of available water (above the volume of rain water fallen during the storm). The significance of this fact when having in mind the restoration of sloping arid lands needs no further elaboration.

5. References

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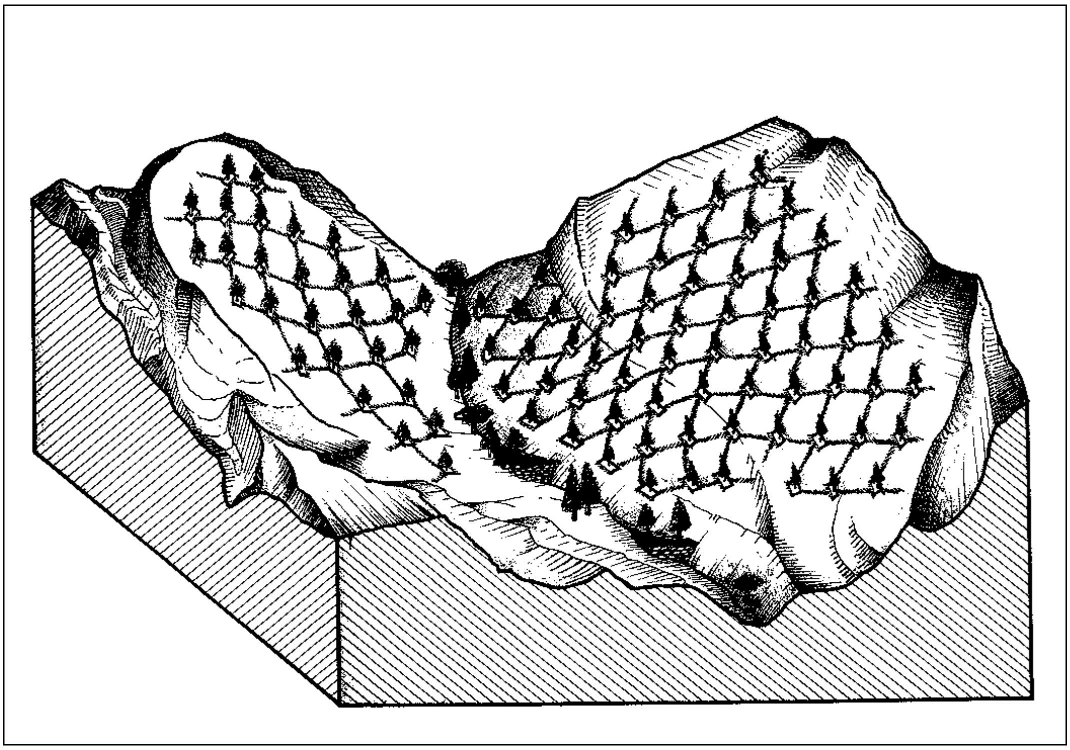
6. Final notes

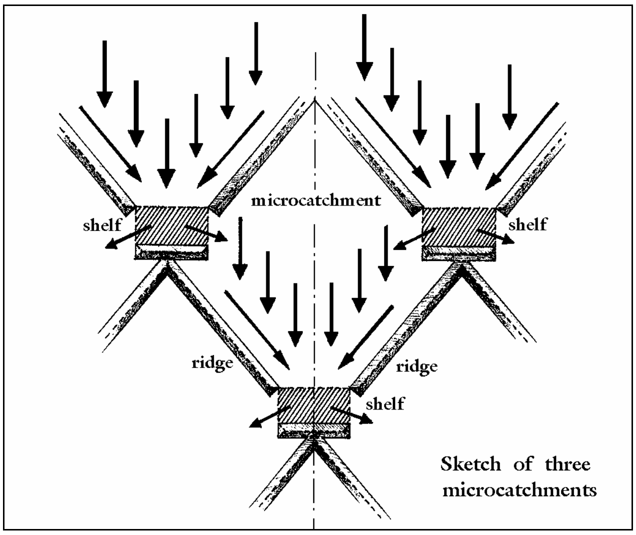
1) MODIPE (version 1.1) and its accompanying user's manual may be obtained through the publication marked thus ***** in the bibliography. Those interested in obtaining an English version of the program should get in touch with the author.
2) This work is a part of the research project entitled "Modelo para la estimación de las disponibilidades hídricas en ladera", financed by ICONA through the LUCDEME project in Spain.
3) The author would like to acknowledge Mr. Alfonso Centeno González for its help in translating this article.

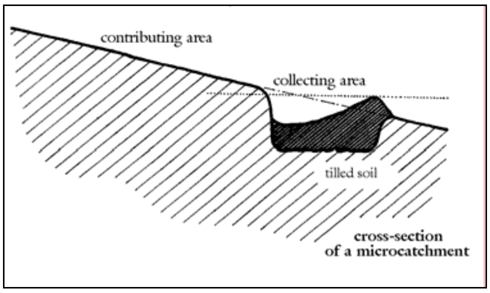
APPENDIX I

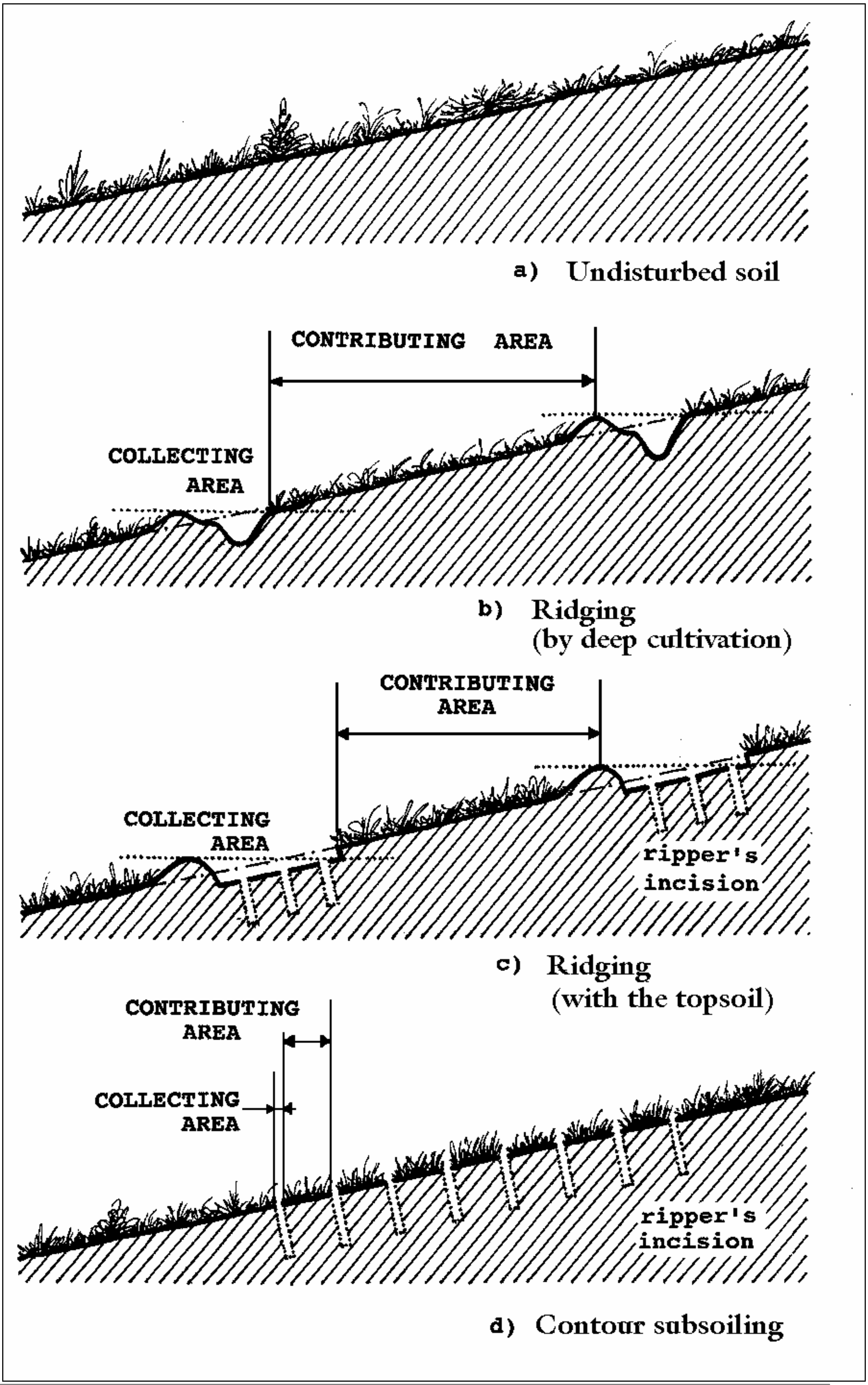
SOME TYPICAL PROCEDURES FOLLOWED IN THE PREPARATION OF THE SOIL FOR REFORESTATION IN SPAIN

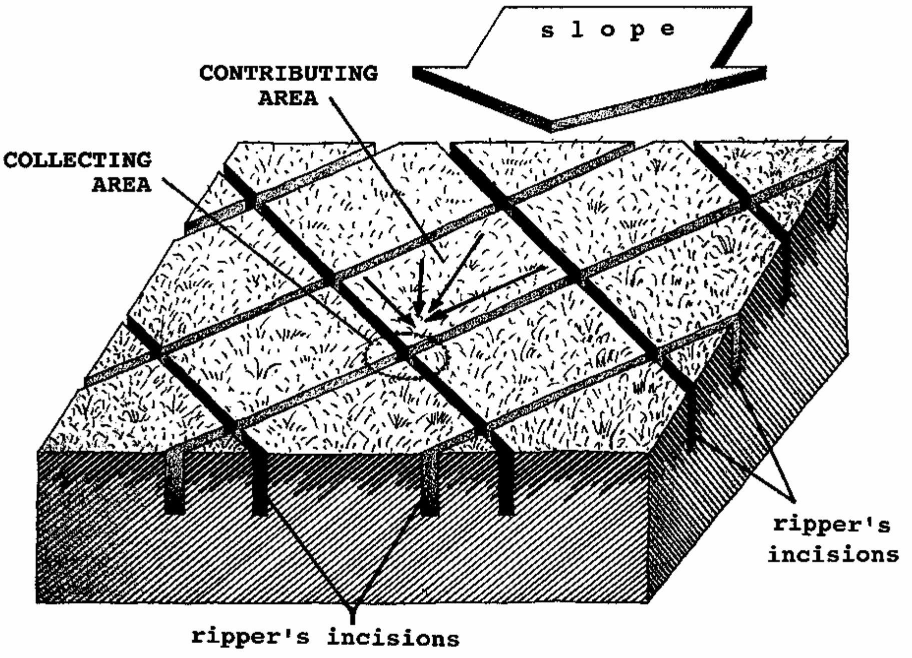


Degraded slope systematized with microcatchments for reforestation

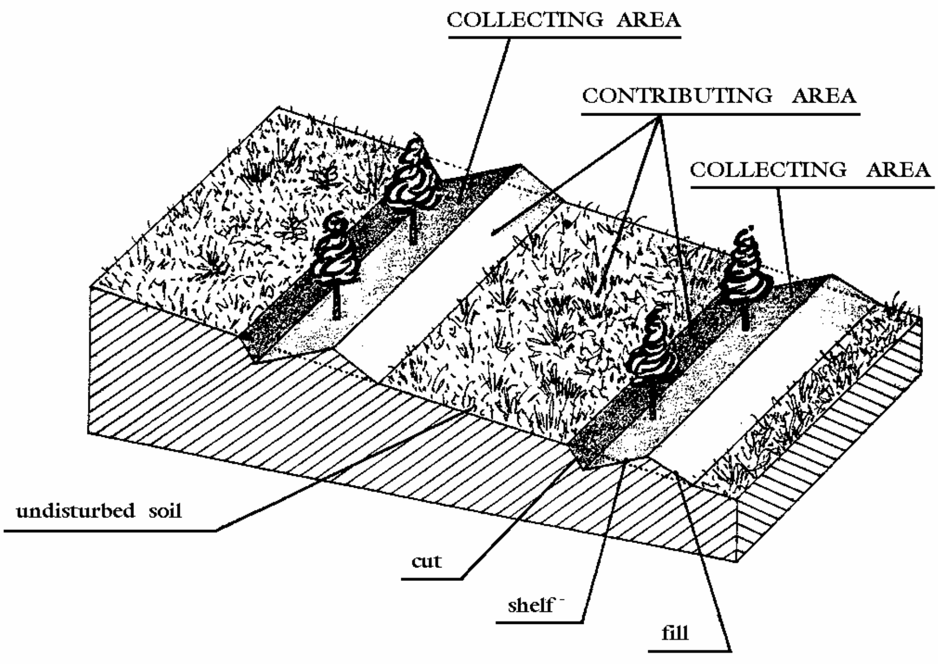





a) Undisturbed soil
CONTRIBUTING AREA
COLLECTING AREA
b) Ridging
(by deep cultivation)
CONTRIBUTING AREA
COLLECTING AREA
ripper's incision
c) Ridging
(with the topsoil)
CONTRIBUTING AREA
COLLECTING AREA
ripper's incision
d) Contour subsoiling



Full subsoiling



Reverse-sloped terraces
(= bench terraces)

APPENDIX II: PRINCIPAL OUTPUT DATA

MODIPE PROGRAM

BASIC DATA OF THE SYSTEMATIZATION

	S m^2	*N1*	*P0*(1) mm	*N2*	*P0*(2) mm	*N3*	*P0*(3) mm
CURRENT SLOPE	-----	77	15	89	6	95	3
CONTRIBUTING AREA	9.0	77	15	89	6	95	3
COLLECTING AREA	1.0	72	20	86	8	93	4
SYSTEMATIZED UNIT	10.0	44	66	54	44	61	32

S = area
N(i) = curve number (in moisture condition i]
P0(i) = runoff threshold (in moisture condition i)

RESERVOIR CAPACITY OF THE COLLECTING AREA: 200.0 l

MODIPE PROGRAM

Precipitation of the storm:
50 mm

Antecedent moisture condition:
1

Available water (mm)

on flat terrain	50
on the current slope	38.8
on a systematized unit	50
on the collecting area	150.7

MINIMUM RESERVOIR CAPACITY OF THE MICROPOND TO RETAIN RUNOFF: 107.3 l