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ENVIRONMENTAL EDUCATION THROUGH THE USE OF EROSIONAL FEATURES

by

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This article is based upon teaching materials prepared for the FAO Southern Africa Training Programme (Overseas Development Group, Norwich) and in preparation for another FAO project in land use and regional planning, Central Province, Zambia.

INTRODUCTION

Deterioration of our environment is one of the most critical and intractable problems that we have to face. Everywhere can be seen the signs of environmental stress; polluted rivers, overgrazed pastures, degraded soils, denuded landscapes and many others. The answers to such problems have been demonstrated to be technically possible, but the symptoms of distress remain. The science of ecology can model the complex linkages between the variables that form the physical environment, but is unable to provide lasting solutions and the decline continues. In seeking to find explanations for the deterioration of the environment, two related points are abundantly clear: first, the very complexity of natural systems makes it difficult to predict the consequences of human actions; and, secondly, it is even more difficult for sometimes strange and foreign concepts in conservation to be accepted by people if they have no basic knowledge of the natural systems that we attempt to manipulate for our mutual benefit.

Increasingly education is seen as the long term key to the preservation of the environment and the provision of the knowledge in ecological principles upon which to construct successful conservation programmes. The International Bank for Reconstruction and Development (the World Bank) is known to be disenchanted with the general failure of development schemes. For example IBRD's Forestry Sector Review in 1978 marked a substantial change in policy in which three of the four areas of interest of the Bank in lending for forestry centred around the preservation of the environment and the strengthening of institutional means of promoting education and research. Similarly, the UN Food and Agriculture Organisation is slowly turning from specific projects, staffed and maintained by expatriates, to training programmes for local nationals and support for basic education in conservation. Within southern Africa, FAO are funding substantial education programmes in Botswana, Lesotho, Swaziland, Malawi and Zambia. Again, disenchantment with the failure of development has led to the search for long term and more basic solutions.

Education is not the whole answer because there may be seemingly rational reasons why farmers permit erosion, even if they understand its causes and its significance. Soil erosion is not necessarily a consequence of ignorance, just as knowledge does not automatically lead to soil conservation as witnessed in some of the massive erosion and environmental problems in the United States. Nevertheless, education is a means of strengthening local participation and understanding in conservation.

However, the problem remains that, if teaching in ecological and environmental matters is to be promoted, how are some of the complex processes and interactions in the physical environment to be introduced and taught with local relevance and meaning? It is all very well talking of the scouring of U-shape valleys by ice or coastal erosion and onshore drift, but in the heart of Africa they have little relevance to the more challenging and important problems surrounding every village school in every rural area.

Soil erosion is one of the symptoms of environmental stress that is readily-discernible in most rural areas. As such it provides a focus for a set of exercises designed to look at some of the key questions in conservation and environmental management:

- what are the basic physical principles governing erosion?
- how serious is environmental deterioration in my area?
- what are the ecological and environmental interactions that cause degradation of the environment?
- why preserve natural resources?
- what practical methods can help to halt deterioration?

This article suggests some simple exercises in which the above questions can be considered. Features of soil erosion - gullies (dongas), rills, sheet erosion, sedimentation, and a host of smaller forms - provide a unique outdoor laboratory and object for study. Obviously, exercises must be adapted for local circumstances but it is hoped that these suggestions will give teachers some ideas upon which to build.

BASIC PHYSICAL PRINCIPLES

Soil erosion occurs when the forces trying to remove soil from the earth's surface are stronger than the forces attempting to resist the removal. It consists of two basic processes:

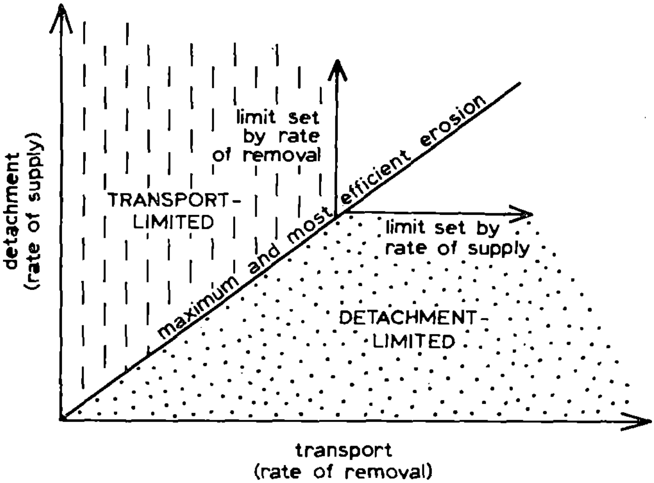


Figure 1 Relationship between transport and detachment in the erosion process (adapted from Thomes, J. B. 1976 'Semi-arid erosional systems', *London School of Economics Geographical Papers* No. 7)

(a) detachment; this is the process whereby a soil particle becomes separated from the main body of soil;

(b) transport; where the detached particle is moved from its source.

Obviously transport cannot occur unless a particle of soil has previously been detached. In addition, detachment cannot cause soil erosion by itself unless transport is operative. This leads to two important conditions in the process of erosion: at one end of the scale there are transport-limited conditions where there is abundant detachment but insufficient transporting capability for those detached particles to be moved away; at the other end of the scale there is detachment - limited conditions where there is spare transporting capability but not enough detachment. This is shown diagrammatically in Figure 1 where the maximum and most efficient rate of erosion set by environmental conditions is represented by an equilibrial line exactly balancing detachment and transport.

Consider the sorts of physical circumstances under which either condition might be operative. It would be useful to demonstrate each in the field. Transport-limited conditions might occur from any one or a combination of the following reasons:

(a) <u>very permeable soil</u>: water infiltrates very quickly and none flows over the ground. Transport is therefore reduced - compare the runoff from water applied by a watering can to trays containing samples of light-coloured sandy soils as against dark heavy clay.

(b) <u>a cohesive soil</u>: how well do the particules of soil stick together? If a soil crumbles easily into its constituent particles, then detachment will occur more easily. If it is sticky, especially when wet, detachment is less likely. However, remember that this is not the whole story - the very fine particles that make up a sticky soil will often float into suspension in water and be transported, and the larger particles in a sandy soil will be too heavy to be transported. These differences and their influence on erosion can also be demonstrated in the field.

(c) <u>a low angle slope</u>: water velocity is reduced and its transporting capability is likewise reduced. This may be demonstrated by simple experience with a watering can on samples of the same soil type in trays held at different angles.

(d) <u>a short slope</u>: if the slope is short there is less opportunity for runoff water to build up on the slope and therefore less capability to transport soil.

(e) <u>surface retention of water</u>: from a variety of causes such as leaf litter, abundant depressions in the surface or simply a newly-ploughed field.

In similar fashion <u>detachment-limited conditions</u> could occur for the following reasons which can also be demonstrated:

(a) <u>vegetation cover</u>: has the effect of absorbing the energy of raindrops which otherwise would have been used in detaching soil particles. This is easily shown by placing a piece of fine netting (mosquito gauze, for instance) over a tray of soil to simulate vegetation, and comparing the runoff and erosion from the covered tray against that from an unprotected tray. Consider why the covered tray reduces erosion and runoff even though exactly the same <u>quantity</u> of water reaches the soil surface.

(b) an impermeable soil.

(c) a loose, friable soil.

(d) a high angle slope.

(e) a long slope.

(f) smooth surface.

By considering the erosion process in this way the effect of any one variable can be examined and discussed. The main variables that one would need to concentrate upon would be the quantity and intensity of water applied (i.e. rainfall and rainfall erosivity), type of soil (soil erodibility), the nature of the protection given to the soil (vegetation cover) and the degree and length of slope. Through all these the basic physical processes can be highlighted.

Another useful method of bringing out basic physical processes is to examine the form of erosional features. This relies upon form being indicative of the processes having produced it - a dangerous assumption academically for it is possible to argue that similar forms may develop by different combinations of process. Nevertheless the assumption is valuable for many features.

Gully forms are particularly good for diagnosing the processes responsible for gully formation. Stocking (1973) describes a range of types of gully head each type indicating a particular process or combination of processes. Some further features are given in Figure 2 including forms that might be found within and around the gully if it is remembered that gullies are a natural reaction to a general imbalance in erosion forces and are nature's way of removing large quantities of runoff water quickly and efficiently - too efficiently for us because a lot of sediment goes with it! - then here will be a host of features of environmental distress, especially in the catchment area to the gully where runoff coalesces. The head cut of the gully (i.e. the point of the gully that is most active and is moving uphill as erosion progresses) represented in Figure 2A and 2B will indicate the processes responsible for the immediate cutting of the gully: it may be channelised flow of water or underground seepage causing slumping. The nature of the soil will play a part: if it is strong and cohesive you will find a steep, angular head cut; if it is weak and structureless you will find much soil debris and slumping. The channel cross-section (Fig. 2C) will also indicate process. A brief survey with measuring tape or by field sketch will help to establish whether the gully is actively incising, or if it has undergone a series of incisions leaving terraces, or if it is aggrading. Look particularly as the cross-section of a gully at a bend, where often will be found the classic features of rivers: a cliff on the outside of the bend

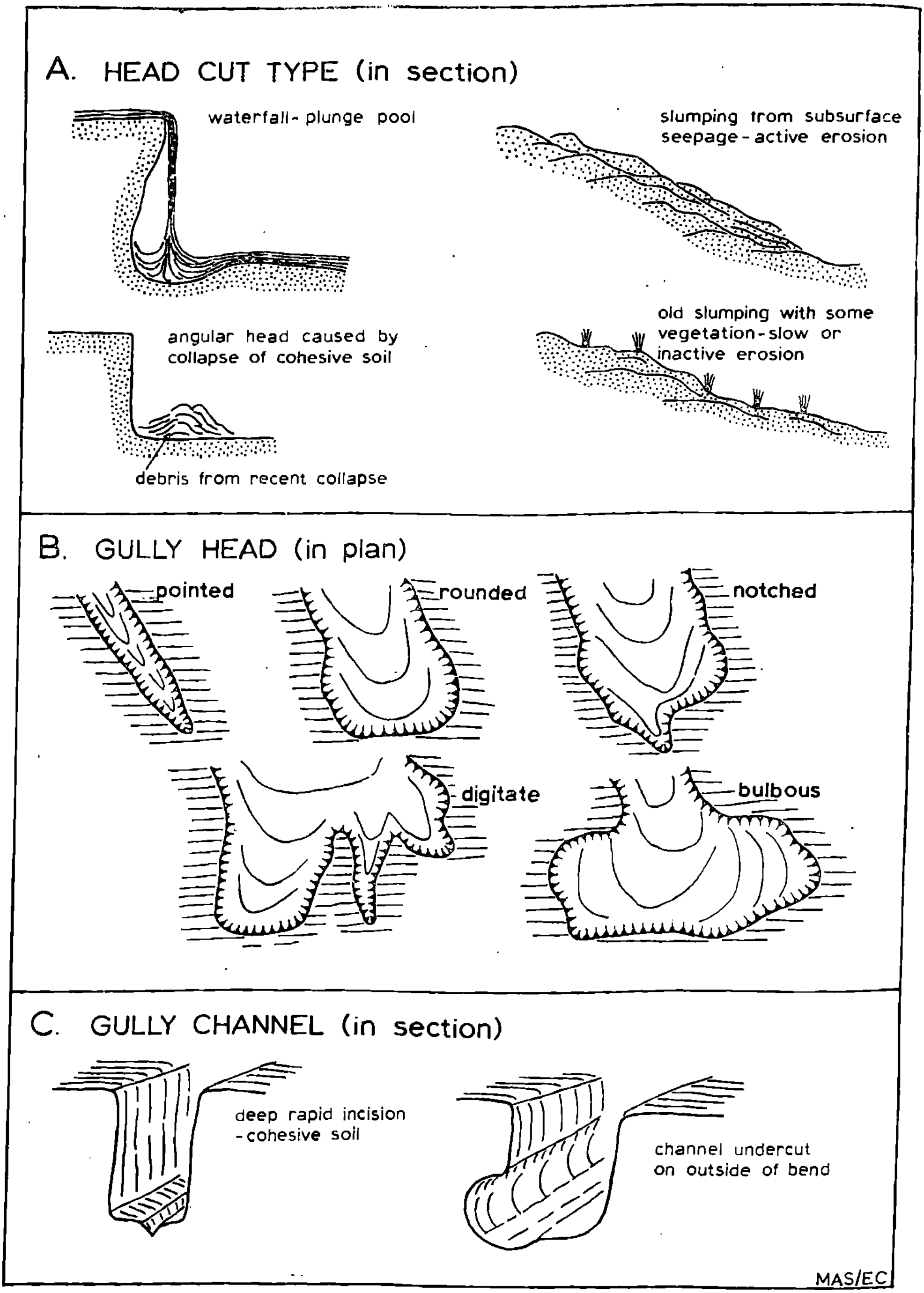


Figure 2 Erosionaı features in a gullied area

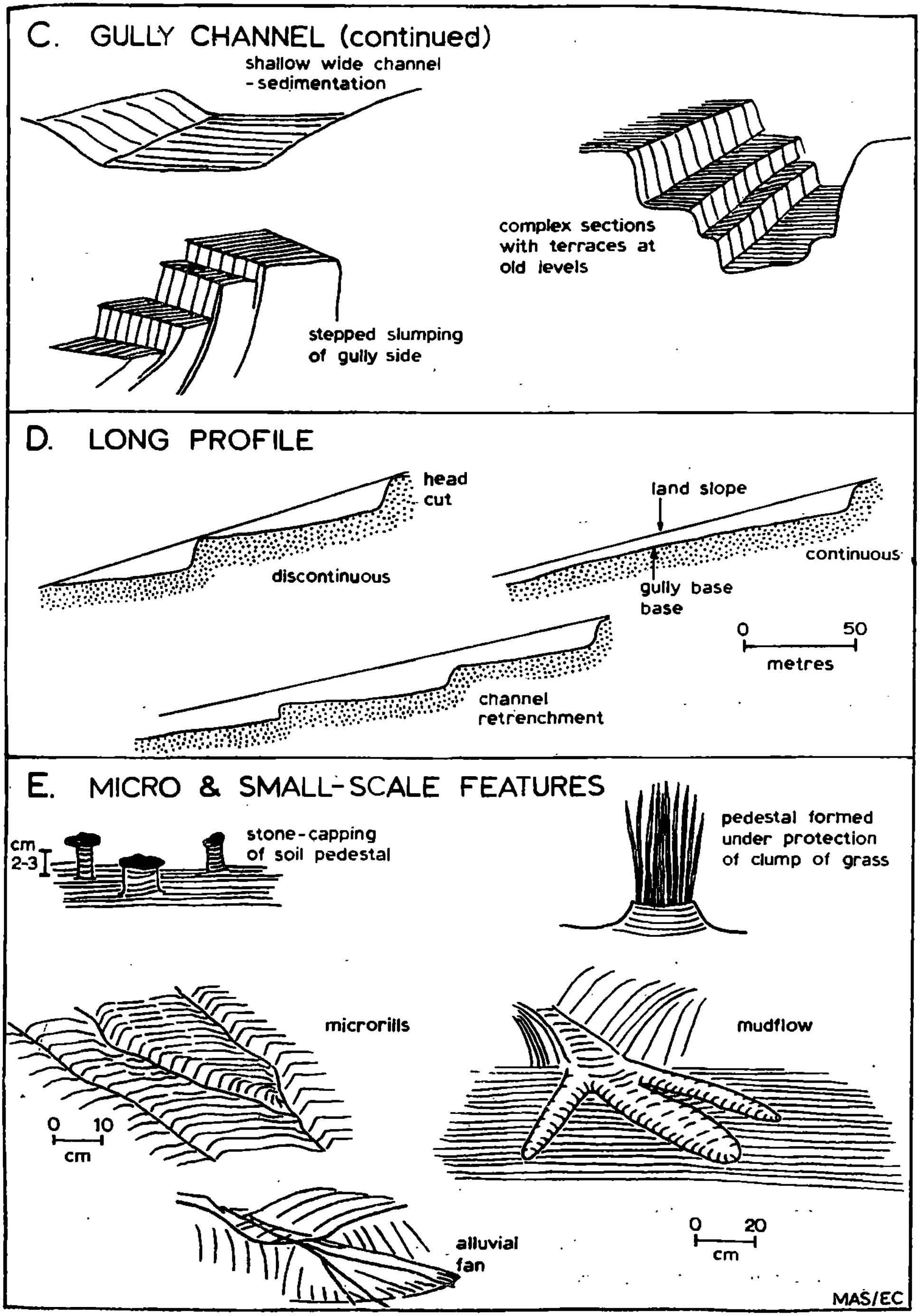


Figure 2 Erosional features in a gullied area (continued)

and a more gentle slope on the inside. The precise position of the channel when water is flowing in it will be obvious and you may even be able to identify the height to which water flows when the gully is in flood by looking carefully for signs such as grass stems caught in tree branches or water marks on the gully side. The long profile of the gully (Fig.2D) gives a wider view of the progress of erosion. Gullies can be classified into continuous or discontinuous: the former are usually more stable and permanent features of the landscape, often on fairly gentle slopes; the latter consist of a series of head cuts advancing uphill along the same route. The construction of a long profile will also reveal whether there have been periods of erosion and retrenchment in the development of the gully. It has been found in Mondoro in central Zimbabwe as well as many other parts of the world that small shifts in climate from a wetter to a drier phase having more intense but less frequent storms have been sufficient to cause renewed incision. Finally, the wide variety of micro-features developed in and around gullies present a valuable opportunity to discuss physical processes: just a few examples are shown in Figure 2E. Soil pedestals, capped by a protecting stone or clump of grass are very common where sheet erosion is dominant; microrills, the precursors to larger rills and eventually gullies, show up small-scale drainage patterns and can illustrate how drainage networks develop on a new surface through river capture; mudflows and alluvial fans will serve to demonstrate how soil movements and deposition of sediment can occur. The potential list of features is enormous and just a little imagination and footwork is needed to utilise the vast range of erosional forms. Features that may seem insignificant present useful opportunities to teach erosional process.

HOW SERIOUS IS ENVIRONMENTAL DETERIORATION?

Living in an area it is difficult to discern that your own environment is deteriorating. Deterioration is normally incremental and rarely catastrophic. It proceeds slowly by degrees and humans, being adaptable, adjust their lives and activities to suit the changing circumstances. Therefore, it is possible to live in what an outsider might call a severely-degraded area and not perceive it oneself. This is particularly true for rural children in the subsistence sector with few opportunities to notice the deteriorating state of the local countryside because no immediate baseline condition is available with which to contrast the changing circumstances. It is imperative that some objective assessment of the seriousness of environmental deterioration should be attempted. Erosional features present opportunities for such an assessment.

The problem is to establish some perceptual baseline condition. This could be an area which shows very few signs of erosion: perhaps a well-conserved mission farm or an area set aside for a different land use where the normal pressures of cattle and humans on the land are not operative. For example, in research into soil erosion in Ngezi (Central Zimbabwe) it was necessary to investigate the change in composition of grass species of the veld caused by overgrazing, the idea being that overgrazing causes a shift towards annual grasses and species that are less palatable to cattle. A baseline condition was found in an ancestral burial area where very little grazing had occurred. The composition of species within the protected area was very different from that outside although soil type and all environmental factors other than grazing pressure were the same.

With a set of two or more prospective sites to compare, it is now possible to consider the question: how serious is the erosion? At an elementary level it is best to tackle that question through an inventory of erosional features. There are certain key features that require examination: some are amenable to being recorded on a presence/absence basis; others would allow simple measurement out in the field to establish their seriousness. It is suggested that a recording sheet be drawn up listing the following:

Site - describe the area you are studying

Large-scale features

Gullies - how many are there? how deep? length?

- do they affect communications by road or footpath?
- have farmers had to relocate their arable or grazing lands because of gullies? Are they threatening any buildings?

Sheet erosion - what signs are there? Bare, unvegetated areas, devoid of topsoil? Soil Pedestals? Residue of coarse sand grains on surface?

what effects have sheet erosion had? Declining crop yield? Poor grasses? Sedimentation at bottom of fields? Infilling of water storages? Dried-up waterholes?

Small-scale features

Rill erosion - as above for gullies

- what signs are there that the rills are developing into gullies?

- where are the rills? Are they on heavily sheet-eroded land or are they aligned along footpaths or cattle trails? Are ther any other associations between rills and human land use?

Microforms: pedestals, fans, arches, soil slumps, tunnels, collapses etc. - note their occurrence and density.

Human factors which influence erosion

Population - how many people directly depend upon this area for their livelihood? By arable farming? By cattle grazing? or other land use? Calculate the approximate population density (people per square kilometre).

Livestock - how many cattle, goats and other livestock use this land? Do any livestock travel through or come specifically to this area to water or dip tank? Calculate livestock density.

Farming practices - any conservation measures? Contour banks? Storm dr

- what is the grazing pressure on grassland? Are there signs of overgrazing (is more than 50% of the soil surface unprotected by grasses?)

- do the farmers have any knowledge/appreciation of conservation and desire to implement protective measures?

Physical factors which influence erosion

Slopes - how steep? how long?

Vegetation - how much protective cover given to the soil? condition of vegetation?

Soil - permeable or impermeable? Does it contain much organic matter?

An inventory such as this helps to categorize each major feature or cause of erosion, and enable one to compare areas with regard to the seriousnes of erosion (Fig.3). There may well be areas where some features, say,

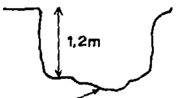
	BASELINE CONDITION	AREA 1	AREA 2
<u>SITE</u>	Mission farm	On slope down to river from Chirisere store	Grazing land by Umzingwane dip
<u>LARGE-SCALE FEATURES</u>			
GULLIES	None	One small gully 0,5m deep, gentle sides; some grass  	One long gully–deeply incised  Small incised channel-footpath now has to deviate around gully
SHEET EROSION	A few sediment deposits from vegetable plots. Otherwise none	Bare degraded areas areas next to river which cattle have overgrazed	Extensive areas of coarse light sand with little vegetation. Abandoned fields. Dried up waterhole

Figure 3 Part of an inventory of erosional features; field sheet for recording information on a comparative basis

gully erosion, are far more prominent than sheet erosion and other areas where the opposite is true. By discussing trade-offs between different categories in the inventory, this will lead to a consideration of what constitutes serious erosion. So is sheet erosion more serious than gully erosion? How does either type of erosion affect our use of land? And so on. Again the opportunities are large for fruitful discussion.

The construction of a comparable inventory of erosional features uses a spatial baseline condition: an area that is relatively little eroded in contrast to one that is more eroded. Another way of tackling the perceptual problem of establishing a baseline condition is to consider erosion as a process occurring over time. If the progress of erosion is faster in one place than another, it would be safe to assume that erosion was more serious in the former place. In many ways this approach is sounder for it leads one to make assertions about erosion based upon current changes rather than the indirect evidence of form and process. Time is, of course, the major limiting problem of this approach, because it will be necessary to monitor changes in erosional features over at least one rainy season and at several times within the season. Nevertheless it would make a suitable environmental project for older children.

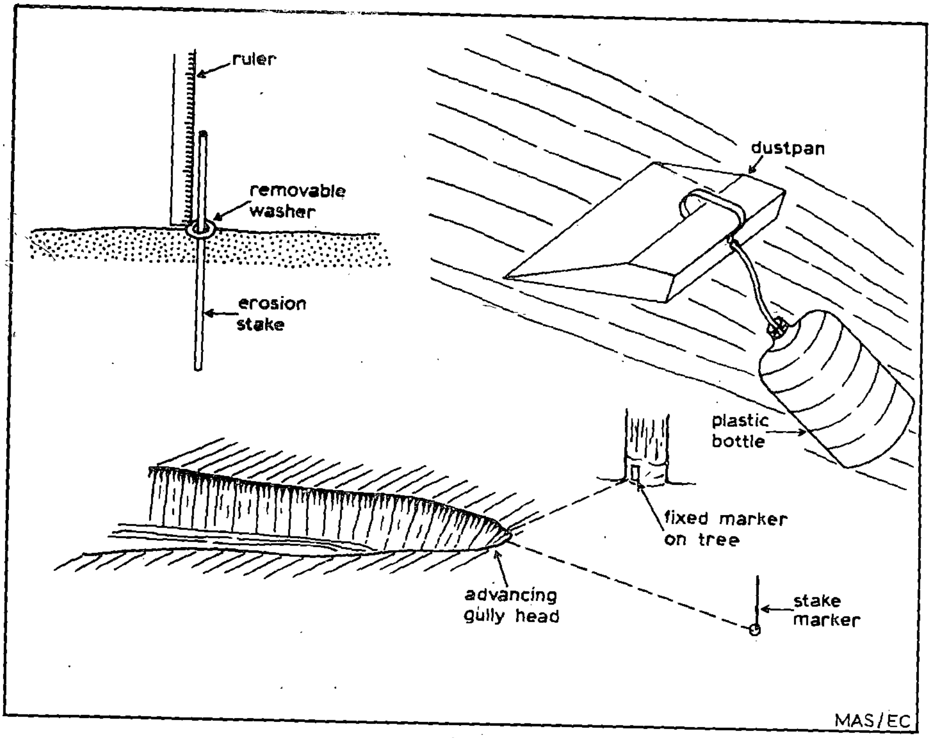


Figure 4 Some examples of simple methods to monitor the rate of erosion

MONITCRING RATES OF EROSION

Three simple methods for monitoring rates of erosion are illustrated in Figure 4. Erosion stakes are in use widely because of their simplicity and cheapness. A stake is hammered into the ground carefully without causing cracks in the soil or undue disturbance until about 10 cm of the stake is left exposed. A washer is slipped over the end of the stake and allowed to rest on the ground. Then with a ruler graduated in millimetres, the length of the exposed stake is measured. Take the washer off and repeat the measurement after every sizeable storm. Plot the rate of lowering of the ground by noting the increasing length of stake. Alternatively aggradation and sedimentation may be occurring and the length of exposed stake may diminish. Several problem arise with this method. The stake should be as thin as possible so that normal erosional processes around it continue unimpeded. It has been found that stakes are often disturbed or stolen: if disturbed it may be that the length you measure suddenly changes for no accountable reason. Results have therefore to be treated with great circumspection. Nevertheless, very useful comparative measurements of sheet erosion are possible.

Erosion traps to monitor sheet wash can be made simply from a dustpan, length of plastic tubing and a large bottle. Placed with its open end uphill and the lip of the pan flush with the soil, any sheet erosion arising from a storm will wash into the pan and be collected in the bottle. It is necessary to empty the trap and bottle at regular intervals, carefully washing out the pan and retaining all the sediment clinging to the inside of the pan, tube and bottle. Let the water evaporate (or if impatient, boil it off) and weigh the dry sediment. Again rainfall events may be related to erosional events. it will probably be that only major storms will create sheet wash. It would therefore be interesting to note how big and how intense the storm has to be before erosion starts. A nearby raingauge at a school or farm, or simply a tin can where the depth of water is measured daily after rainfall would suffice to give an idea of quantities of rainfall on at least a daily basis.

The third method illustrated in Figure 4 using fixed markers is an ideal way to monitor the rate of movement of a gully head. The markers could be stakes, trees, boulders or any other fixed object from which an accurate linear measure may be made to the nearest point at the head of the gully. Figure 5 shows how the results might be plotted and placed in relation to rainfall events. Interesting questions can arise from such diagrams: why, for example, does one intense storm fail to produce any movement of the gully head, whereas several days of less intense rainfall produced a massive advance? Observations of the state of the gully head including occurrence of soil falls and collapses would assist in the interpretation of the data.

In the final analysis it would be good to consider how serious environmental deterioration is in (a) a static, physical way in, for example, comparing the amounts of land rendered useless, severely impaired, slightly impaired and unharmed; (b) in a dynamic physical way by contrasting rates of erosion; and (c) in the effect of erosion on our lives. Some issues in this latter category will be dealt with later when considering notions and perceptions as to the preservation of resources.

WHAT ARE THE ECOLOGICAL AND ENVIRONMENTAL INTERACTIONS THAT CAUSE DEGRADATION?

It is tempting to look at processes in the environment as being specific cause-and-effect interactions. So, for example, in the infiltration of water in the soil it is common practice to represent this purely as a

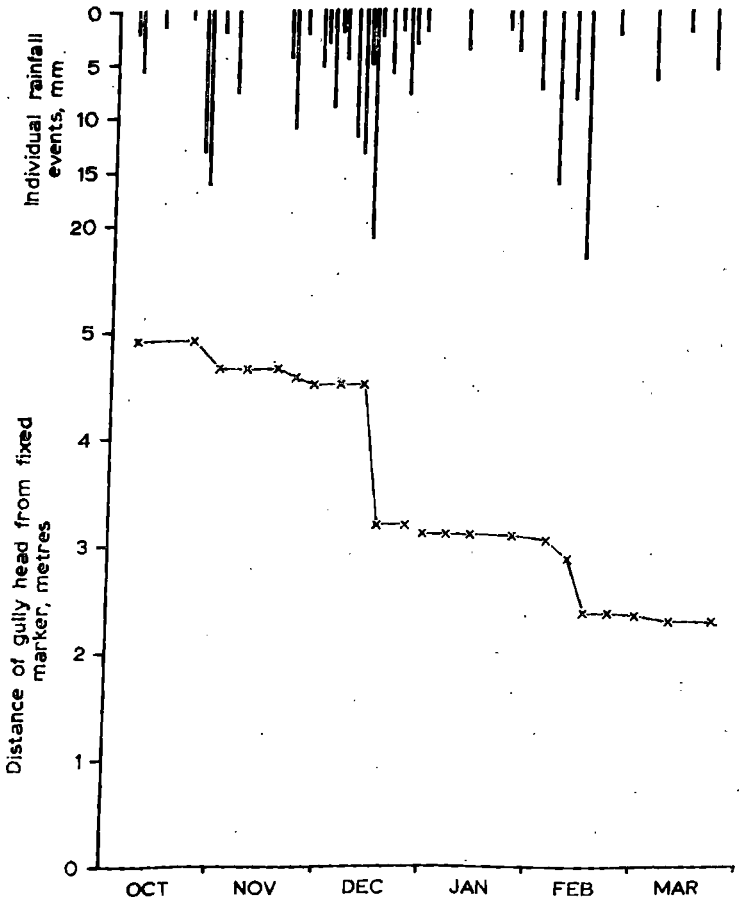


Figure 5 Progress of gully advancement in relation to rainfall events (hypothetical)

function of time: infiltration being great at the start of wetting and dropping off rapidly to some stable condition (Fig.6). Time is of paramount importance and controls the amount of water infiltrating at any given moment, but other factors are also influenctial in determining the degree of infiltration: soil texture is a function of the size of the pore spaces through which the water passes (Fig.6A); management practices also affect the structural properties of the soil (Fig.6B); and a good vegetation cover promotes greater infiltration (Fig.6C).

This example of the infiltration of water into the soil is of direct relevance to the process of erosion: if infiltration can be encouraged, there will be less water to runoff and therefore less erosion. But there is

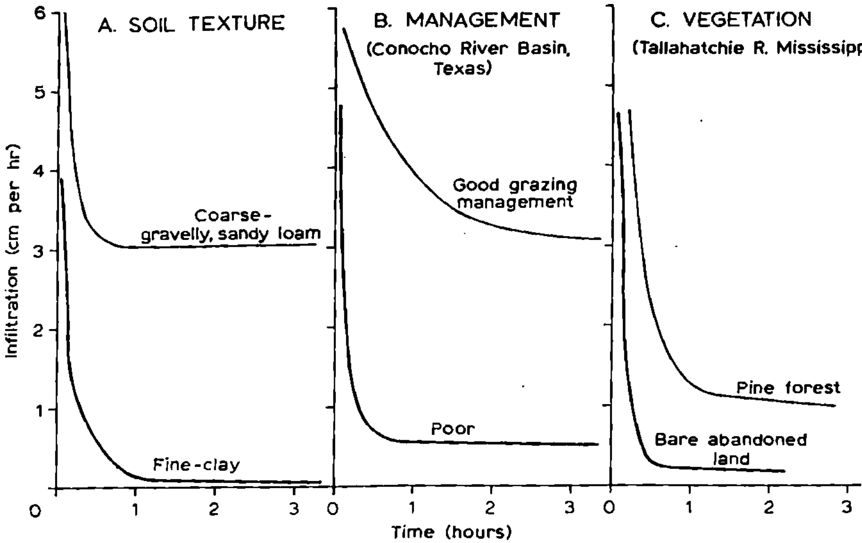


Figure 6 Infiltration of water into the soil: comparison of three influential factors (data from E. E. Foster 1949 *Rainfall and runoff* Macmillan)

also a general point to be made. In environmental processes there are always a host of influences on any interaction, resulting in a complex reaction which is very difficult to unravel. It is therefore unrealistic to divide the real world into isolated compartments of cause-and-effect, even though there may be some dominant factors in any one process. In the infiltration example we have isolated four factors - soil texture, management, vegetation and time - but there are several more which might have included ground slope, organic matter content and perhaps many subsets of the factors already mentioned. The problem in environmental education is to try to convey this essential characteristic of complexity to the student without confusing the whole issue.

One powerful way of conveying a model of the real world is through the use of a systems diagram. The idea is to represent all the factors in any process in their relative position, indicating their strengths and weaknesses where possible, and their influence on other variables. For soil erosion it is useful to distinguish between three groups of forces:

> energy forces; those factors which control how much energy can be applied in detachment and transport;

resistive forces; those that help to overcome the applied energy forces;

protective forces; those factors that act to divert energy forces into harmless pursuits, and which generally provide the best possibilities of manipulation.

A systems diagram of the erosion process based upon this threefold division of forces is suggested in Figure 7. In order to reduce the complexity of the diagram some interactions are ignored, especially where they do not have an immediate bearing on the balance between the three forces. For example, rainfall distribution obviously influences vegetation cover but this is not shown. Nevertheless the picture that is presented remains complex and drives home two important facts:

(i) erosion is the end result of a complex set of interactive forces;

(ii) the interactive forces are in turn the result of complex sets of interacting variables.

In the diagram (Fig.7) each box represents a variable whose value depends upon local environmental circumstances and which contributes in some greater or lesser degree to the overall erosion hazard. If the value of the variable errs to the left of the scale (e.g. LOW raindrop energy), erosion hazard is for that variable less. Conversely, if the value tends to the right, hazard is high. The erosion that finally results will be the net effect of the values of the variables in each box in the systems diagram.

How could such a diagram be used in environmental education? There are a variety of ways depending upon educational level. At its simplest the balance between the core elements of energy, protective and resistive forces can be discussed. Erosion is a work process requiring energy to overcome a resistance. The applied energy available to overcome the resistance is screened by protective forces. If E is the sum of the energy forces, R the sum of the resistive forces and P the sum of the protective forces, erosion will occur if $E > R$. But part of the natural energy forces may be reduced by protective forces such that erosion will only happen if: $E - P > R$. The object of soil conservation is to make P and R so large that: $P + R > E$ and no erosion will result.

A pebble on a rough inclined board, simulating a soil particle on a sloping field, serves to demonstrate simply the operation of the three forces. What will make the 'soil particle' move? In other words what

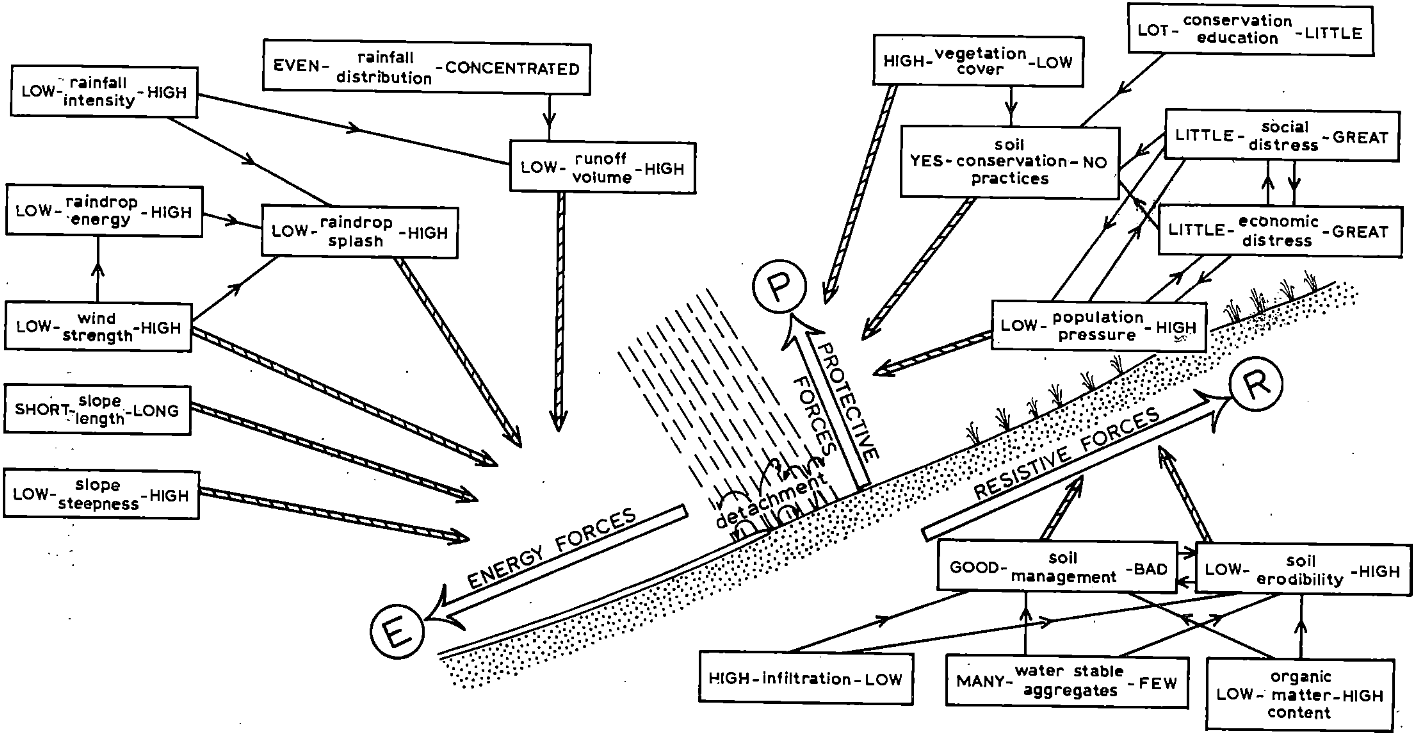


Figure 7 A systems diagram of some of the interactions in the process of erosion

will make energy forces overcome the resistive forces of friction between pebble and board? Naturally, tipping the board to represent a soil particle on a steep field will cause the pebble to move. Other ways would be substituting a smoother board, or rolling another pebble onto the first, or pouring water down the board. The protective forces can be simulated by, for example, substituting a series of steps instead of the board (i.e. contoured bench terraces), or reducing the impact of the rolling pebble, or placing a series of obstacles (twigs, grass) to catch the pebble and stop it rolling any further.

At a more advanced level various combinations of values of the individual variables in the systems diagram might be considered. Determine subjectively what the values for your local area might be. Maps of some of the factors in erosion in Zimbabwe have been published by Stocking and Elwell (1973) and they would assist in assessing the relative value of some of the variables.

The final goal is an appreciation of the complexity of the environment, an understanding of the balances that are operative in the environment, and an awareness that environmental degradation can be the result of many combinations of causes. No universal explanation (e.g. ignorance and misuse of the land) can account for degraded landscapes: degradation and erosion are merely the symptoms of environmental stress. And where these symptoms become serious, then they turn full circle to become the causes of more degradation and more erosion (Fig.3). In such a manner, a vicious cycle is constructed in which distress encourages degradation, and degradation brings yet more distress. That perhaps is the most important ecological and environmental interaction to be taught.

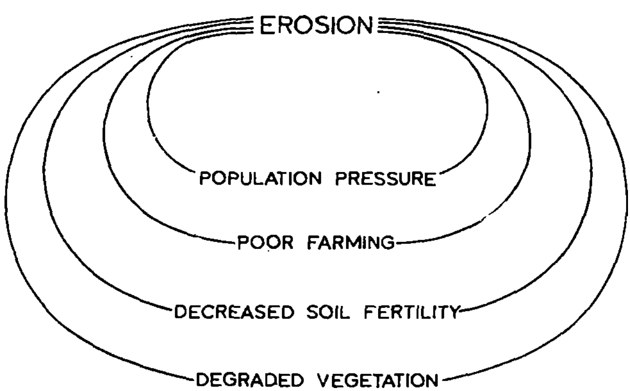


Figure 8 Vicious cycles in erosion

WHY PRESERVE NATURAL RESOURCES?

The immediate answer to the question 'Why preserve natural resources?' is self-interest. However there are other answers. Less tangible reasons concern notions of the long term preservation of the environment being 'a good thing', thoughts that we are the guardians of our physical heritage and must maintain it for future generations, and ideas of landscape aesthetics and the beauty of nature.

These notions are essentially cultural products of society and they develop with an appreciation of one's surroundings. In societies reliant upon a direct relationship between man and nature (e.g. hunter-gatherers, or subsistence farmers), the notions manifest themselves in poetry and oral literature, and traditions develop which effectively preserve natural resources. While soil degradation has featured throughout history and can even partially account for the collapse of some civilizations (e.g. Mayan of Central America, the ancient civilizations centred around the Tigris and Euphrates) most societies have developed practical methods of conservation. In Africa, multicropping and intercropping - the mixed planting of different crops on the same plot at the same time - has many advantages. Not only does it protect from risk of crop failure, it also provides a better and more continuous protection to the soil, is up to twice as efficient as monoculture in the conversion of solar radiant energy into usable calories of food, and it minimises the area to be cleared for agriculture.

In Western ideology the notion develops rather differently. It is manifest in the resurgence of 'ecological movements' especially in France and Germany whose concern rests not so much with a direct interest in and reliance upon the environment (for the roots of the movement are dominantly white, urban, middleclass) but with radical protest in the increasing drift to material values, capitalist production, technology and the wasteful depletion of natural resources. The point to note is not that these notions exist but that we all of us have an innate cultural bias <u>towards</u> the preservation of resources. It is debateable, therefore, whether or not they can be taught formally. However, the threat to our cultural controls upon environmental degradation are from such things as anti-social practices (e.g. cultivation of steep mountain slopes causing floods and sedimentation on the plains below), short-term self-interest (e.g. overgrazing) or economic and political subjugation (e.g. patterns of land tenure fixed for national or local reasons). The reinstatement of the natural inclination of society to preserve resources most therefore stem from the very threat, and appeal to self-interest and the improvement of personal and communal living standards.

Pragmatically, then self-interest is the key to education in the concepts of resource management, allocation and use. The educator should seek the immediate benefits of preserving the environment. With an appreciation of these benefits, only then is it advisable to look to deeper, cultural answers to the question 'Why preserve natural resources'.

Soil erosion is an ideal subject for demonstrating the benefits of conservation. Consider first the human consequences of soil erosion. Table 1 indicates a possible sequence in a scenario of soil erosion that stems from an initial population increase taking the total population above the safe carrying capacity of the land:

This is only an example of one possible sequence. Others could be imagined where, for example, the severe social disruption leads to a short-term political solution such as land redistribution. It would be instructive to ponder on whether possible solutions to the inexorable decline to starvation do anything other than postpone slightly the progression in the sequence.

Where does soil conservation fit into the scenario? A dispassionate analysis of where exactly your local area is in the sequence would be interesting. It may be that your area displays partial evidence of several steps in the sequence simultaneously. What are the solutions? Clearly conservation is most appropriate at the very first steps in reducing the rate of decrease of soil fertility and controlling the rate of population increase. At any other step conservation can only tinker with a system that is already spiralling out of control. Nevertheless many of the steps are reversible. If the initial problems of decline of fertility and increase of population can be halted then political organization could, for example, help solve problems of land competition, or scientific advances in range management can help to halt the degradation of grasslands and reduce grazing pressures. Good conservation is not then a piecemeal input of resources by such measures as better farm management. It should be a frontal approach at every link in the chain, but especially at the first.

Discussion and explanation of these sorts of issues can help gain appreciation of our immediate self-interest in preserving resources and in the long-term a feeling and understanding for the environment.

TABLE 1

declining soil fertility: the fertile fraction of the soil rests in the main in the finer particles of soil (silt, clay organic matter); these are the first to be removed by erosion.

declining crop and grassland productivity: with the fertility reduced the supply of nutrients to the plant is reduced.

A. CHANGES IN LAND USE

increasing area of cultivated land: reduced crop yields force farmers to cultivate more land.

increasing area of grazing land: reduced grassland productivity necessitates a greater area of grassland per animal

B. LAND COMPETITION

overcropping: intensive production methods cause further decrease in fertility.

overgrazing: cattle numbers fixed for social and economic reasons. Palatable and nutritive grass species eaten out.

degradation of arable lands: poor vegetation cover provides little protection from erosion.

degradation of grassland: palatable species replaced by discontinuous cover of woody shrubs; more erosion results.

crop failures: excessive runoff and lack of soil fertility cause crop failure in a season of low rainfall.

cattle deaths: cattle in poor condition and eventually die in a season of low rainfall.

C. SEVERE SOCIAL DISRUPTION

reliance upon imported food
dissatisfaction with allotted amount of land
breakdown of society and kinship bonds
rivalry and war
disruption of lines of supply for food
starvation

WHAT PRACTICAL METHODS CAN HELP HALT DETERIORATION?

The discussion so far has been aimed at building an appreciation for the environment and a want to preserve it. These ideas are prerequisites for the final step in motivating a person to carry out practical methods in conserving the environment.

Again soil erosion provides a ready means for demonstrating reversals in its process and for school projects aimed at rehabilitating eroded areas. In order to succeed, environmental education cannot merely be the establishment of a body of theory: it must be shown to work. Bearing in mind that the maintenance of soil fertility is a key to conservation, one simple and direct experiment is to compare the yields of a maize crop on adjacent small plots. One plot may have been producing crops for some time and have had no inputs of fertiliser or manure; the other plot will be thoroughly composted before planting. Comparative data for the two plots can be recorded as in Figure 9. It could be calculated how many of each type of plot would be required to feed a family for a year. The difference in growth patterns between Plots A and B would allow a greater proportion of the energy of falling rain to strike bare ground and cause detachment. The difference in yields indicate that the fertility status of the two soils differ and that other things being equal a poor soil promotes more erosion than a good one.

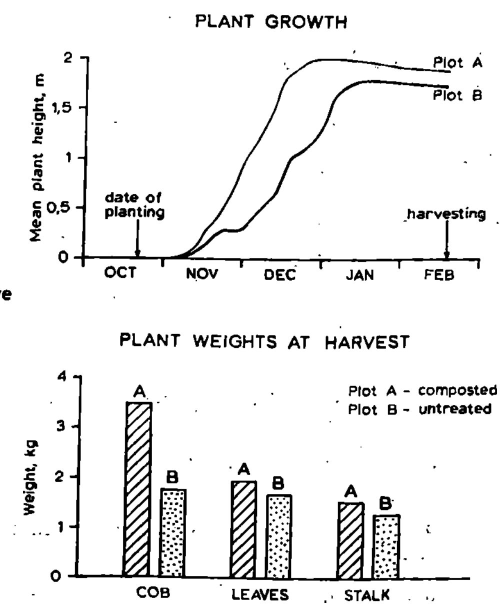


Figure 9: Comparative data on a simple plot experiment

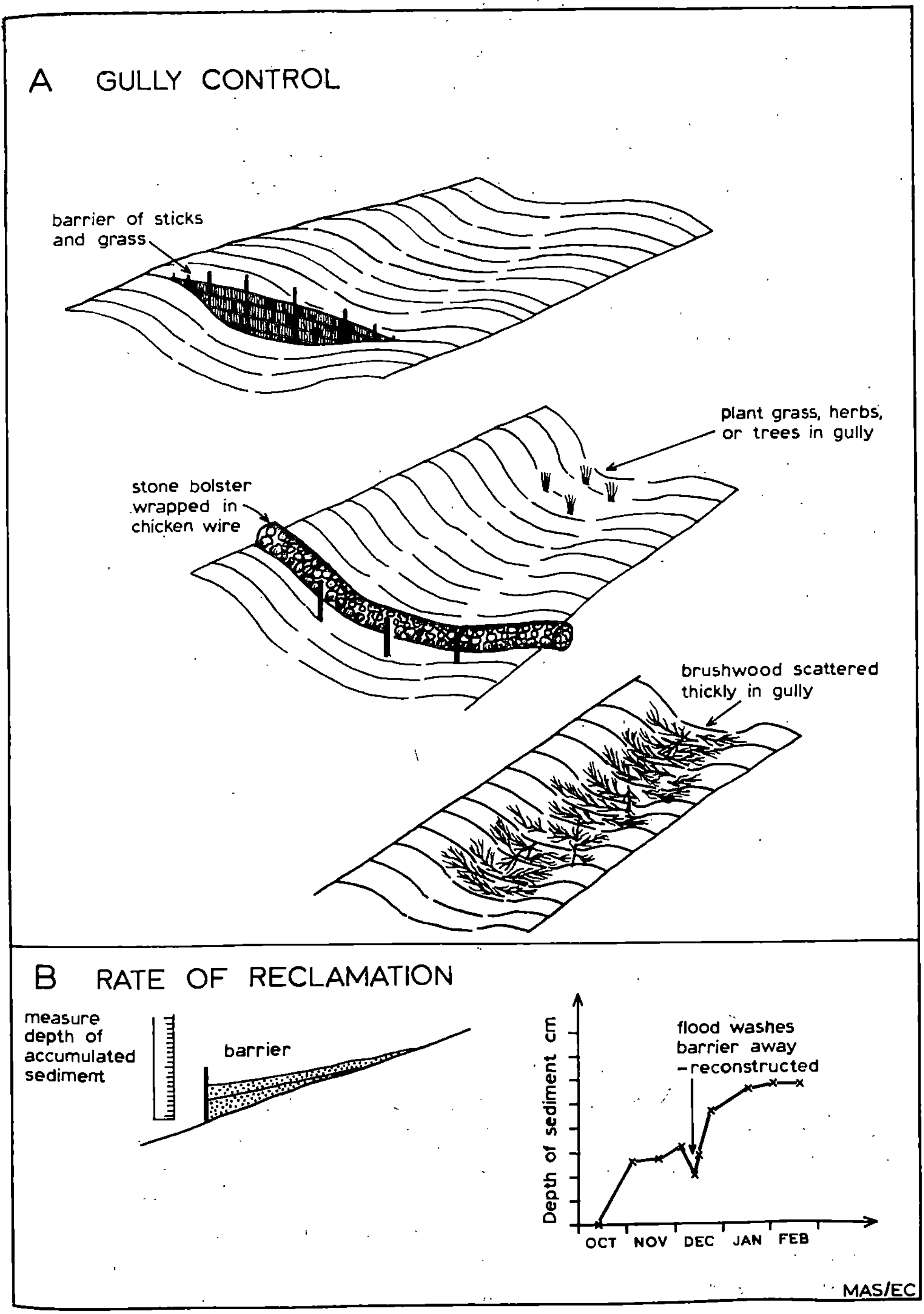


Figure 10 Simple methods of Promoting gully sedimentation

Educational projects can also utilise gullies. If it is considered that a gully is merely a channel along which water and sediment travels, a means of retarding the flow of water would encourage it to drop its load of sediment and the gully would gradually infill. The most obvious way of doing this is to construct a porous barrier across the gully so that the water can pass through slowly but leave its load of sediment. The accumulation of sediment will in turn reduce the gradient of the floor of the gully and further encourage the water to drop its load. Barriers of sticks and grass are sometimes used, but they are often swept away in the exceptionally heavy storm. More substantial barriers of stones wrapped in chicken wire are common (Fig. 10A). Other methods include the placing of brushwood along the gully to trap sediment and planting grass sisal or even trees in the base of the gully. Indeed tree-planting to rehabilitate gullies is a common practice in Swaziland where the local community maintains the plantation as a source of fuel wood and building material. Again this illustrates the incidental but nonetheless direct benefits that conservation can bring if planned with a feeling for the needs of the community. The catchment to the gully must also be a focus for concern because it is here that runoff waters concentrate.

The best way to minimise this build-up of water is to control grazing and land use pressures in the catchment to allow grass to regenerate and consequently promote the better infiltration of water.

Gully control can be exceedingly frustrating. Structures built by conservation engineers are often washed away and destroyed. However, it is possible to heal many smaller gullies with the simple methods outlined in Figure 10 especially if this is co-ordinated with improvements in the catchment to the gully. Finally, it is valuable to monitor the rate at which sedimentation is occurring. This is best achieved by measuring the depth of accumulated sediment next to the barrier (Fig. 10B).

CONCLUSION

Environmental education is being increasingly stressed because of the obvious degradation of the environment all around us. It finds a place in curricula for geography, biology and agriculture courses where it is imperative that students find interesting and absorbing experiments and projects to undertake. I hope that this article may provide a few ideas for teachers on practicable field work, as well as giving a useful conceptual framework around which to build an appreciation for the environment. Comments and feedback on the success or otherwise of these and other exercises in environmental education would be most appreciated by the author.

ACKNOWLEDGEMENT

Nick Abel gave very useful comments on a draft of this paper.

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ENVIRONMENTAL EDUCATION THROUGH THE USE OF EROSIONAL FEATURES

by

M. Stocking

This article is based upon teaching materials prepared for the FAO Southern Africa Training Programme (Overseas Development Group, Norwich) and in preparation for another FAO project in land use and regional planning, Central Province, Zambia.

INTRODUCTION

Deterioration of our environment is one of the most critical and intractable problems that we have to face. Everywhere can be seen the signs of environmental stress; polluted rivers, overgrazed pastures, degraded soils, denuded landscapes and many others. The answers to such problems have been demonstrated to be technically possible, but the symptoms of distress remain. The science of ecology can model the complex linkages between the variables that form the physical environment, but is unable to provide lasting solutions and the decline continues. In seeking to find explanations for the deterioration of the environment, two related points are abundantly clear: first, the very complexity of natural systems makes it difficult to predict the consequences of human actions; and, secondly, it is even more difficult for sometimes strange and foreign concepts in conservation to be accepted by people if they have no basic knowledge of the natural systems that we attempt to manipulate for our mutual benefit.

Increasingly education is seen as the long term key to the preservation of the environment and the provision of the knowledge in ecological principles upon which to construct successful conservation programmes. The International Bank for Reconstruction and Development (the World Bank) is known to be disenchanted with the general failure of development schemes. For example IBRD's Forestry Sector Review in 1978 marked a substantial change in policy in which three of the four areas of interest of the Bank in lending for forestry centred around the preservation of the environment and the strengthening of institutional means of promoting education and research. Similarly, the UN Food and Agriculture Organisation is slowly turning from specific projects, staffed and maintained by expatriates, to training programmes for local nationals and support for basic education in conservation. Within southern Africa, FAO are funding substantial education programmes in Botswana, Lesotho, Swaziland, Malawi and Zambia. Again, disenchantment with the failure of development has led to the search for long term and more basic solutions.

Education is not the whole answer because there may be seemingly rational reasons why farmers permit erosion, even if they understand its causes and its significance. Soil erosion is not necessarily a consequence of ignorance, just as knowledge does not automatically lead to soil conservation as witnessed in some of the massive erosion and environmental problems in the United States. Nevertheless, education is a means of strengthening local participation and understanding in conservation.

However, the problem remains that, if teaching in ecological and environmental matters is to be promoted, how are some of the complex processes and interactions in the physical environment to be introduced and taught with local relevance and meaning? It is all very well talking of the scouring of U-shape valleys by ice or coastal erosion and onshore drift, but in the heart of Africa they have little relevance to the more challenging and important problems surrounding every village school in every rural area.

Soil erosion is one of the symptoms of environmental stress that is readily-discernible in most rural areas. As such it provides a focus for a set of exercises designed to look at some of the key questions in conservation and environmental management:

- what are the basic physical principles governing erosion?
- how serious is environmental deterioration in my area?
- what are the ecological and environmental interactions that cause degradation of the environment?
- why preserve natural resources?
- what practical methods can help to halt deterioration?

This article suggests some simple exercises in which the above questions can be considered. Features of soil erosion - gullies (dongas), rills, sheet erosion, sedimentation, and a host of smaller forms - provide a unique outdoor laboratory and object for study. Obviously, exercises must be adapted for local circumstances but it is hoped that these suggestions will give teachers some ideas upon which to build.

BASIC PHYSICAL PRINCIPLES

Soil erosion occurs when the forces trying to remove soil from the earth's surface are stronger than the forces attempting to resist the removal. It consists of two basic processes:

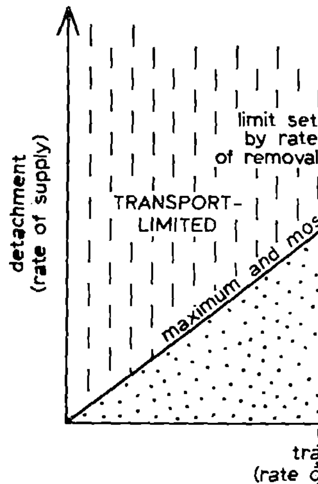

Figure 1 Relationship be
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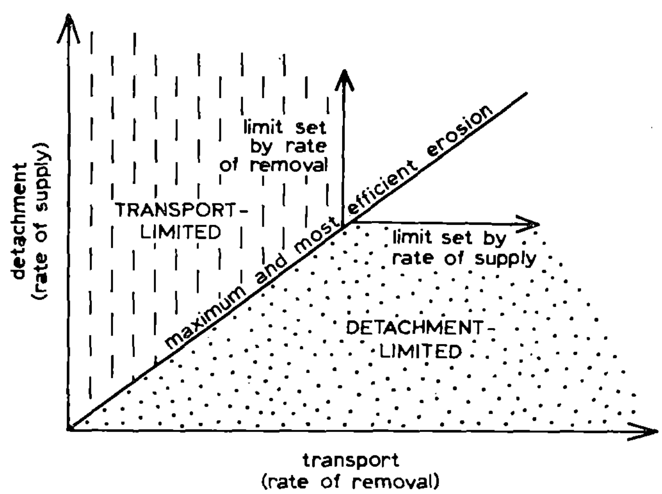

Figure 1 Relationship between transport and detachment in the erosion process (adapted from Thornes, J. B. 1976 'Semi-arid erosional systems', *London School of Economics Geographical Papers* No. 7)

(a) detachment; this is the process whereby a soil particle becomes separated from the main body of soil;

(b) transport; where the detached particle is moved from its source.

Obviously transport cannot occur unless a particle of soil has previously been detached. In addition, detachment cannot cause soil erosion by itself unless transport is operative. This leads to two important conditions in the process of erosion: at one end of the scale there are transport-limited conditions where there is abundant detachment but insufficient transporting capability for those detached particles to be moved away; at the other end of the scale there is detachment - limited conditions where there is spare transporting capability but not enough detachment. This is shown diagrammatically in Figure 1 where the maximum and most efficient rate of erosion set by environmental conditions is represented by an equilibrial line exactly balancing detachment and transport.

Consider the sorts of physical circumstances under which either condition might be operative. It would be useful to demonstrate each in the field. Transport-limited conditions might occur from any one or a combination of the following reasons:

(a) very permeable soil: water infiltrates very quickly and none flows over the ground. Transport is therefore reduced - compare the runoff from water applied by a watering can to trays containing samples of light-coloured sandy soils as against dark heavy clay.

(b) a cohesive soil: how well do the particules of soil stick together? If a soil crumbles easily into its constituent particles, then detachment will occur more easily. If it is sticky, especially when wet, detachment is less likely. However, remember that this is not the whole story - the very fine particles that make up a sticky soil will often float into suspension in water and be transported, and the larger particles in a sandy soil will be too heavy to be transported. These differences and their influence on erosion can also be demonstrated in the field.

(c) a low angle slope: water velocity is reduced and its transporting capability is likewise reduced. This may be demonstrated by simple experience with a watering can on samples of the same soil type in trays held at different angles.

(d) a short slope: if the slope is short there is less opportunity for runoff water to build up on the slope and therefore less capability to transport soil.

(e) surface retention of water: from a variety of causes such as leaf litter, abundant depressions in the surface or simply a newly-ploughed field.

In similar fashion detachment-limited conditions could occur for the following reasons which can also be demonstrated:

(a) vegetation cover: has the effect of absorbing the energy of raindrops which otherwise would have been used in detaching soil particles. This is easily shown by placing a piece of fine netting (mosquito gauze, for instance) over a tray of soil to simulate vegetation, and comparing the runoff and erosion from the covered tray against that from an unprotected tray. Consider why the covered tray reduces erosion and runoff even though exactly the same quantity of water reaches the soil surface.

(b) an impermeable soil.

(c) a loose, friable soil.

(d) a high angle slope.

(e) a long slope.

(f) smooth surface.

By considering the erosion process in this way
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concentrate upon would be the quantity and inte
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Gully forms are particularly good for diagnosi
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Look particularly as the cross-section of
be found the classic features of rivers:

(c) a loose, friable soil.

(d) a high angle slope.

(e) a long slope.

(f) smooth surface.

By considering the erosion process in this way the effect of any one variable can be examined and discussed. The main variables that one would need to concentrate upon would be the quantity and intensity of water applied (i.e. rainfall and rainfall erosivity), type of soil (soil erodibility), the nature of the protection given to the soil (vegetation cover) and the degree and length of slope. Through all these the basic physical processes can be highlighted.

Another useful method of bringing out basic physical processes is to examine the form of erosional features. This relies upon form being indicative of the processes having produced it - a dangerous assumption academically for it is possible to argue that similar forms may develop by different combinations of process. Nevertheless the assumption is valuable for many features.

Gully forms are particularly good for diagnosing the processes responsible for gully formation. Stocking (1973) describes a range of types of gully head each type indicating a particular process or combination of processes. Some further features are given in Figure 2 including forms that might be found within and around the gully if it is remembered that gullies are a natural reaction to a general imbalance in erosion forces and are nature's way of removing large quantities of runoff water quickly and efficiently - too efficiently for us because a lot of sediment goes with it! - then here will be a host of features of environmental distress, especially in the catchment area to the gully where runoff coalesces. The head cut of the gully (i.e. the point of the gully that is most active and is moving uphill as erosion progresses) represented in Figure 2A and 2B will indicate the processes responsible for the immediate cutting of the gully: it may be channelised flow of water or underground seepage causing slumping. The nature of the soil will play a part: if it is strong and cohesive you will find a steep, angular head cut; if it is weak and structureless you will find much soil debris and slumping. The channel cross-section (Fig. 2C) will also indicate process. A brief survey with measuring tape or by field sketch will help to establish whether the gully is actively incising, or if it has undergone a series of incisions leaving terraces, or if it is aggrading. Look particularly as the cross-section of a gully at a bend, where often will be found the classic features of rivers: a cliff on the outside of the bend

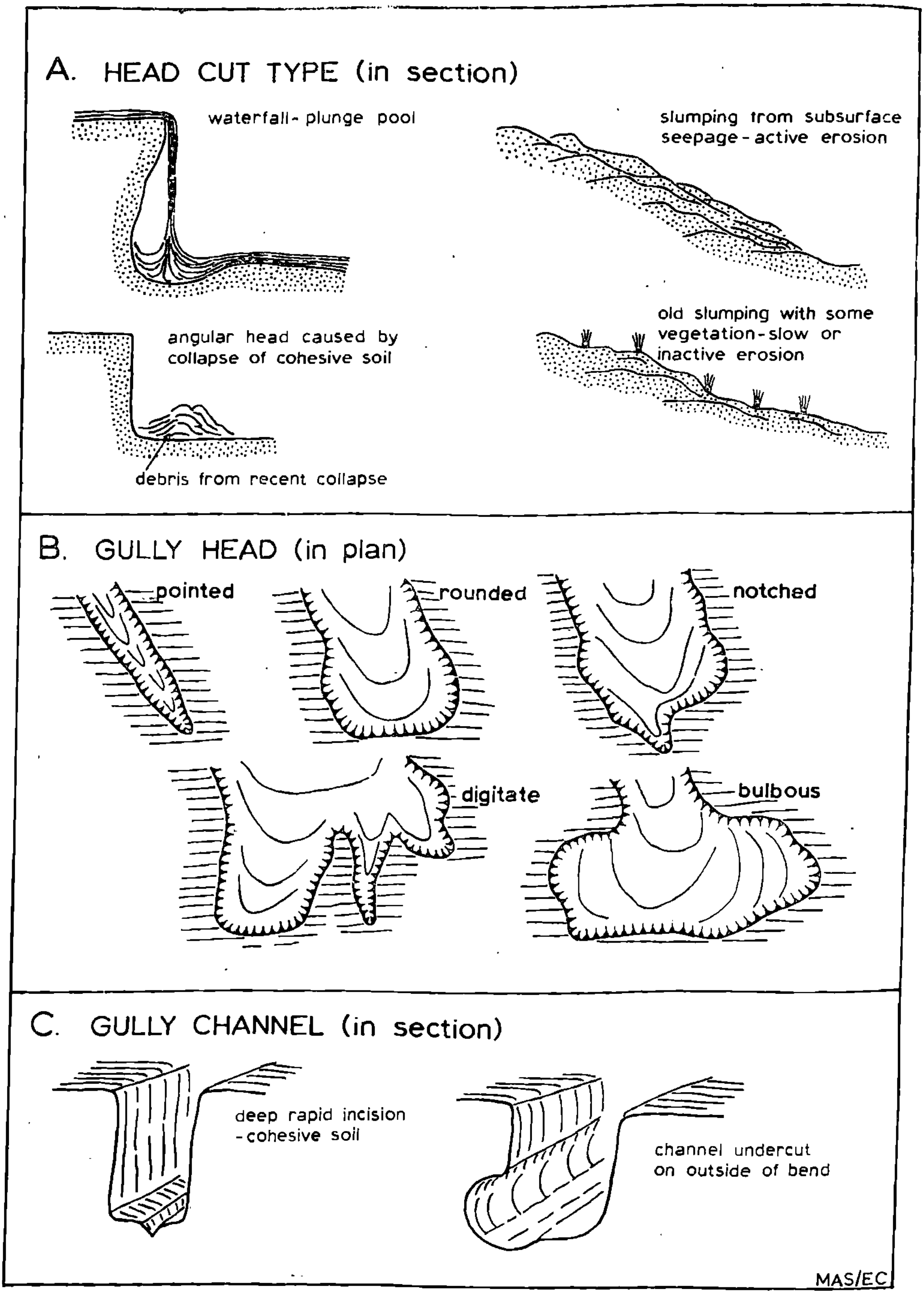

Figure 2 Erosional features in a gullied area

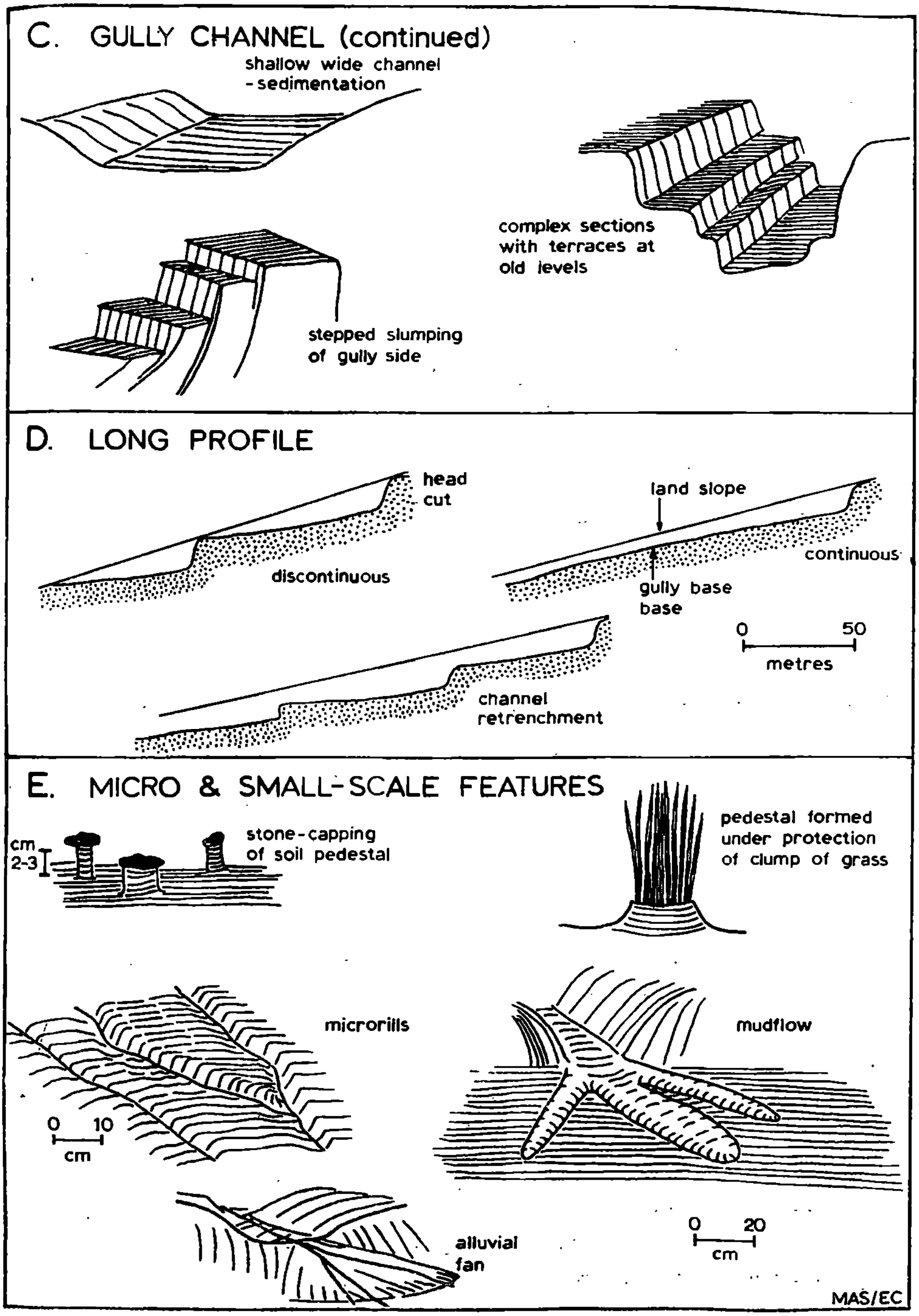

Figure 2 Erosional features in a gullied area (continued)

and a more gentle slope on the inside. The precise position of the channel when water is flowing in it will be obvious and you may even be able to identify the height to which water flows when the gully is in flood by looking carefully for signs such as grass stems caught in tree branches or water marks on the gully side. The long profile of the gully (Fig.2D) gives a wider view of the progress of erosion. Gullies can be classified into continuous or discontinuous: the former are usually more stable and permanent features of the landscape, often on fairly gentle slopes; the latter consist of a series of head cuts advancing uphill along the same route. The construction of a long profile will also reveal whether there have been periods of erosion and retrenchment in the development of the gully. It has been found in Mondoro in central Zimbabwe as well as many other parts of the world that small shifts in climate from a wetter to a drier phase having more intense but less frequent storms have been sufficient to cause renewed incision. Finally, the wide variety of micro-features developed in and around gullies present a valuable opportunity to discuss physical processes: just a few examples are shown in Figure 2E. Soil pedestals, capped by a protecting stone or clump of grass are very common where sheet erosion is dominant; microrills, the precursors to larger rills and eventually gullies, show up small-scale drainage patterns and can illustrate how drainage networks develop on a new surface through river capture; mudflows and alluvial fans will serve to demonstrate how soil movements and deposition of sediment can occur. The potential list of features is enormous and just a little imagination and footwork is needed to utilise the vast range of erosional forms. Features that may seem insignificant present useful opportunities to teach erosional process.

HOW SERIOUS IS ENVIRONMENTAL DETERIORATION?

Living in an area it is difficult to discern that your own environment is deteriorating. Deterioration is normally incremental and rarely catastrophic. It proceeds slowly by degrees and humans, being adaptable, adjust their lives and activities to suit the changing circumstances. Therefore, it is possible to live in what an outsider might call a severely-degraded area and not perceive it oneself. This is particularly true for rural children in the subsistence sector with few opportunities to notice the deteriorating state of the local countryside because no immediate baseline condition is available with which to contrast the changing circumstances. It is imperative that some objective assessment of the seriousness of environmental deterioration should be attempted. Erosional features present opportunities for such an assessment.

The problem is to establish some percep
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Site - describe the area you are stu

Large-scale features

Gullies - how many are there? h

- do they affect communic

- have farmers had to rel
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Sheet erosion - what signs are th
devoid of topsoil?
coarse sand grains on

what effects have she
yield? Poor grasses?
Infilling of water st

Small-scale features

Rill erosion - as above for gullies

The problem is to establish some perceptual baseline condition. This could be an area which shows very few signs of erosion: perhaps a well-conserved mission farm or an area set aside for a different land use where the normal pressures of cattle and humans on the land are not operative. For example, in research into soil erosion in Ngezi (Central Zimbabwe) it was necessary to investigate the change in composition of grass species of the veld caused by overgrazing, the idea being that overgrazing causes a shift towards annual grasses and species that are less palatable to cattle. A baseline condition was found in an ancestral burial area where very little grazing had occurred. The composition of species within the protected area was very different from that outside although soil type and all environmental factors other than grazing pressure were the same.

With a set of two or more prospective sites to compare, it is now possible to consider the question: how serious is the erosion? At an elementary level it is best to tackle that question through an inventory of erosional features. There are certain key features that require examination: some are amenable to being recorded on a presence/absence basis; others would allow simple measurement out in the field to establish their seriousness. It is suggested that a recording sheet be drawn up listing the following:

Site - describe the area you are studying

Large-scale features

Gullies - how many are there? how deep? length?

- do they affect communications by road or footpath?
- have farmers had to relocate their arable or grazing lands because of gullies? Are they threatening any buildings?

Sheet erosion - what signs are there? Bare, unvegetated areas, devoid of topsoil? Soil Pedestals? Residue of coarse sand grains on surface?

what effects have sheet erosion had? Declining crop yield? Poor grasses? Sedimentation at bottom of fields? Infilling of water storages? Dried-up waterholes?

Small-scale features

Rill erosion - as above for gullies

- what signs are there that the rills are developing into gullies?

- where are the rills? Are they on heavily sheet-eroded land or are they aligned along footpaths or cattle trails? Are there any other associations between rills and human land use?

Microforms: pedestals, fans, arches, soil slumps, tunnels, collapses etc. - note their occurrence and density.

Human factors which influence erosion

Population - how many people directly depend upon this area for their livelihood? By arable farming? By cattle grazing? or other land use? Calculate the approximate population density (people per square kilometre).

Livestock - how many cattle, goats and other livestock use this land? Do any livestock travel through or come specifically to this area to water or dip tank? Calculate livestock density.

Farming practices - any conservation measures? Contour banks? Storm drains?

- what is the grazing pressure on grassland? Are there signs of overgrazing (is more than 50% of the soil surface unprotected by grasses?)

- do the farmers have any knowledge/appreciation of conservation and desire to implement protective measures?

Physical factors which influence erosion

Slopes - how steep? how long?

Vegetation - how much protective cover given to the soil? condition of vegetation?

Soil - permeable or impermeable? Does it contain much organic matter?

An inventory such as this helps to categorize each major feature or cause of erosion, and enable one to compare areas with regard to the seriousness of erosion (Fig.3). There may well be areas where some features, say,

	BASELINE CONDITION
SITE	Mission farm
LARGE-SCALE FEATURES	
GULLIES	None
SHEET EROSION	A few sediment deposits from vegetable plots. Otherwise none

Figure 3 Part of an inventory of
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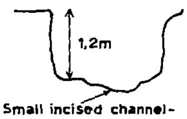
	BASELINE CONDITION	AREA 1	AREA 2
<u>SITE</u>	Mission farm	On slope down to river from Chirisere store	Grazing land by Umzingwane dip
<u>LARGE-SCALE FEATURES</u>			
GULLIES	None	One small gully 0,5m deep, gentle sides; some grass	One long gully–deeply incised
			
SHEET EROSION	A few sediment deposits from vegetable plots. Otherwise none	Bare degraded areas areas next to river which cattle have overgrazed	Extensive areas of coarse light sand with little vegetation. Abandoned fields. Dried up waterhole

Figure 3 Part of an inventory of erosional features; field sheet for recording information on a comparative basis

gully erosion, are far more prominent than sheet erosion and other areas where the opposite is true. By discussing trade-offs between different categories in the inventory, this will lead to a consideration of what constitutes serious erosion. So is sheet erosion more serious than gully erosion? How does either type of erosion affect our use of land? And so on. Again the opportunities are large for fruitful discussion.

The construction of a comparable inventory of erosional features uses a spatial baseline condition: an area that is relatively little eroded in contrast to one that is more eroded. Another way of tackling the perceptual problem of establishing a baseline condition is to consider erosion as a process occurring over time. If the progress of erosion is faster in one place than another, it would be safe to assume that erosion was more serious in the former place. In many ways this approach is sounder for it leads one to make assertions about erosion based upon current changes rather than the indirect evidence of form and process. Time is, of course, the major limiting problem of this approach, because it will be necessary to monitor changes in erosional features over at least one rainy season and at several times within the season. Nevertheless it would make a suitable environmental project for older children.

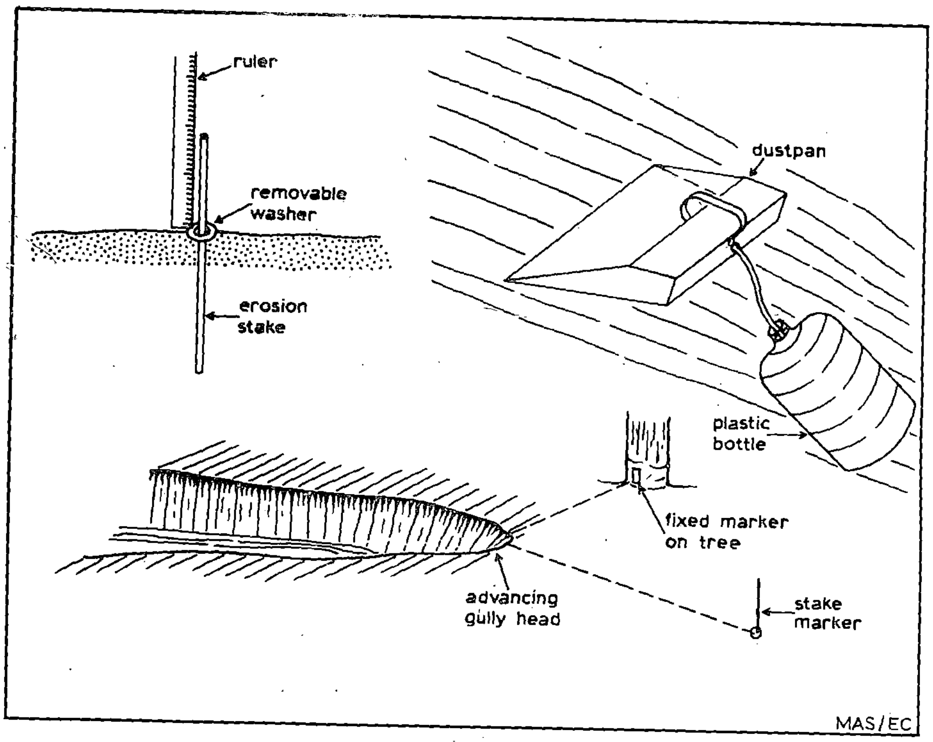


Figure 4 Some examples of simple methods to monitor the rate of erosion

MONITORING RATES OF EROSION

Three simple methods for monitoring rates of erosion are illustrated in Figure 4. Erosion stakes are in use widely because of their simplicity and cheapness. A stake is hammered into the ground carefully without causing cracks in the soil or undue disturbance until about 10 cm of the stake is left exposed. A washer is slipped over the end of the stake and allowed to rest on the ground. Then with a ruler graduated in millimetres, the length of the exposed stake is measured. Take the washer off and repeat the measurement after every sizeable storm. Plot the rate of lowering of the ground by noting the increasing length of stake. Alternatively aggradation and sedimentation may be occurring and the length of exposed stake may diminish. Several problem arise with this method. The stake should be as thin as possible so that normal erosional processes around it continue unimpeded. It has been found that stakes are often disturbed or stolen: if disturbed it may be that the length you measure suddenly changes for no accountable reason. Results have therefore to be treated with great circumspection. Nevertheless, very useful comparative measurements of sheet erosion are possible.

Erosion traps to monitor sheet wash c
length of plastic tubing and a large
uphill and the lip of the pan flush w
arising from a storm will wash into t
bottle. It is necessary to empty the
intervals, carefully washing out the
clinging to the inside of the pan, tu
evaporate (or if impatient, boil it o
Again rainfall events may be related
be that only major storms will create
interesting to note how big and how i
erosion starts. A nearby raingauge a
can where the depth of water is measur
to give an idea of quantities of rain

The third method illustrated in Figur
way to monitor the rate of movement o
be stakes, trees, boulders or any oth
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Figure 5 shows how the results might
rainfall events. Interesting questi
for example, does one intense storm
gully head, whereas several days of
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In the final analysis it would be g
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WHAT ARE THE ECOLOGICAL AND ENVIR
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Erosion traps to monitor sheet wash can be made simply from a dustpan, length of plastic tubing and a large bottle. Placed with its open end uphill and the lip of the pan flush with the soil, any sheet erosion arising from a storm will wash into the pan and be collected in the bottle. It is necessary to empty the trap and bottle at regular intervals, carefully washing out the pan and retaining all the sediment clinging to the inside of the pan, tube and bottle. Let the water evaporate (or if impatient, boil it off) and weigh the dry sediment. Again rainfall events may be related to erosional events. it will probably be that only major storms will create sheet wash. It would therefore be interesting to note how big and how intense the storm has to be before erosion starts. A nearby raingauge at a school or farm, or simply a tin can where the depth of water is measured daily after rainfall would suffice to give an idea of quantities of rainfall on at least a daily basis.

The third method illustrated in Figure 4 using fixed markers is an ideal way to monitor the rate of movement of a gully head. The markers could be stakes, trees, boulders or any other fixed object from which an accurate linear measure may be made to the nearest point at the head of the gully. Figure 5 shows how the results might be plotted and placed in relation to rainfall events. Interesting questions can arise from such diagrams: why, for example, does one intense storm fail to produce any movement of the gully head, whereas several days of less intense rainfall produced a massive advance? Observations of the state of the gully head including occurrence of soil falls and collapses would assist in the interpretation of the data.

In the final analysis it would be good to consider how serious environmental deterioration is in (a) a static, physical way in, for example, comparing the amounts of land rendered useless, severely impaired, slightly impaired and unharmed; (b) in a dynamic physical way by contrasting rates of erosion; and (c) in the effect of erosion on our lives. Some issues in this latter category will be dealt with later when considering notions and perceptions as to the preservation of resources.

WHAT ARE THE ECOLOGICAL AND ENVIRONMENTAL INTERACTIONS THAT CAUSE DEGRADATION?

It is tempting to look at processes in the environment as being specific cause-and-effect interactions. So, for example, in the infiltration of water in the soil it is common practice to represent this purely as a

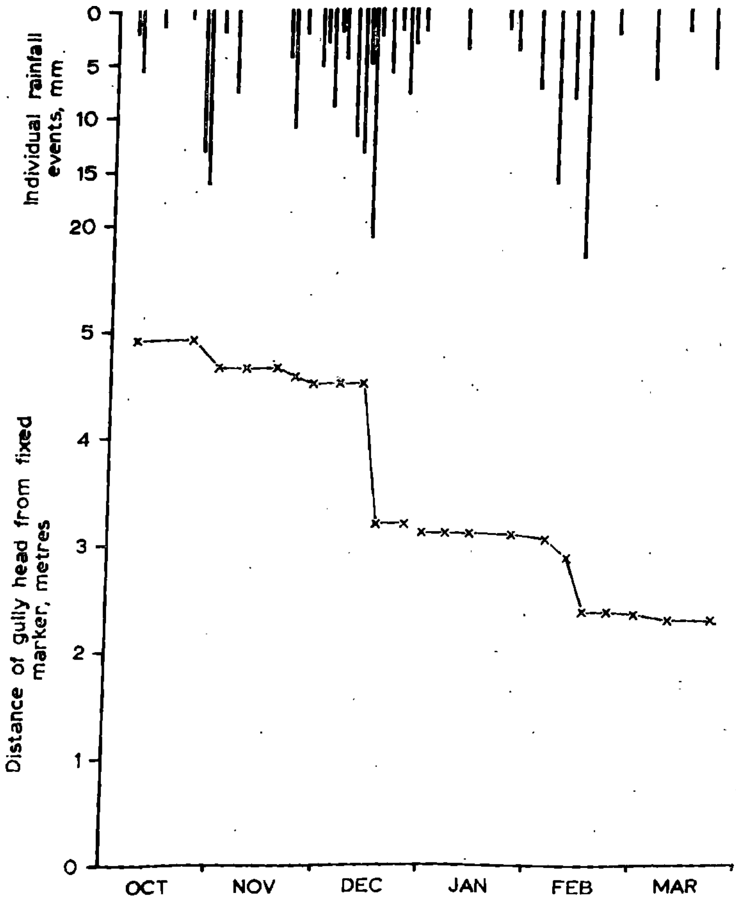

Figure 5 Progress of gully advancement in relation to rainfall events (hypothetical)

function of time: infiltration being great at the start of wetting and dropping off rapidly to some stable condition (Fig.6). Time is of paramount importance and controls the amount of water infiltrating at any given moment, but other factors are also influenctial in determining the degree of infiltration: soil texture is a function of the size of the pore spaces through which the water passes (Fig.6A); management practices also affect the structural properties of the soil (Fig.6B); and a good vegetation cover promotes greater infiltration (Fig.6C).

This example of the infiltration of water into the soil is of direct relevance to the process of erosion: if infiltration can be encouraged, there will be less water to runoff and therefore less erosion. But there is

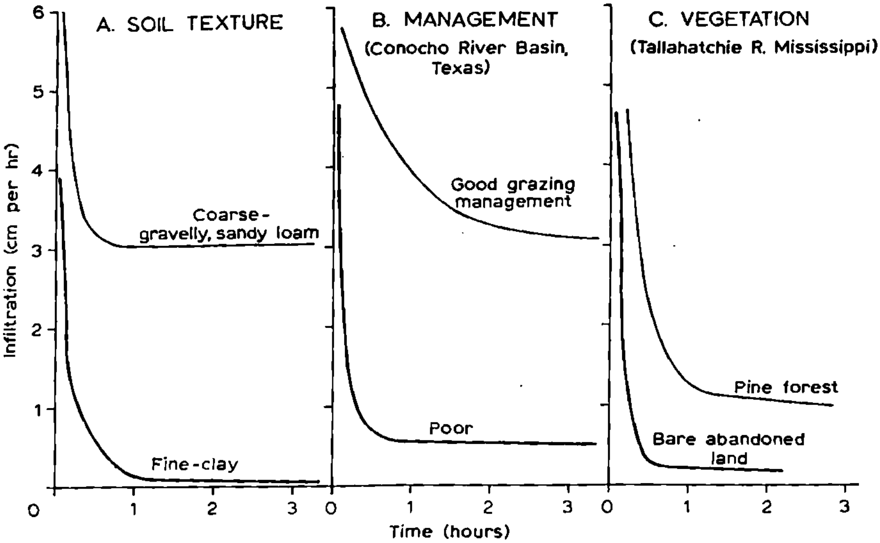

Figure 6 Infiltration of water into the soil: comparison of three influential factors (data from E. E. Foster 1949 *Rainfall and runoff* Macmillan)

also a general point to be made. In environmental processes there are always a host of influences on any interaction, resulting in a complex reaction which is very difficult to unravel. It is therefore unrealistic to divide the real world into isolated compartments of cause-and-effect, even though there may be some dominant factors in any one process. In the infiltration example we have isolated four factors - soil texture, management, vegetation and time - but there are several more which might have included ground slope, organic matter content and perhaps many subsets of the factors already mentioned. The problem in environmental education is to try to convey this essential characteristic of complexity to the student without confusing the whole issue.

One powerful way of conveying a model of the real world is through the use of a systems diagram. The idea is to represent all the factors in any process in their relative position, indicating their strengths and weaknesses where possible, and their influence on other variables. For soil erosion it is useful to distinguish between three groups of forces:

> energy forces; those factors which control how much energy can be applied in detachment and transport;

resistive forces; those that help to overcome the applied energy forces;

protective forces; those factors that act to divert energy forces into harmless pursuits, and which generally provide the best possibilities of manipulation.

A systems diagram of the erosion process based upon this threefold division of forces is suggested in Figure 7. In order to reduce the complexity of the diagram some interactions are ignored, especially where they do not have an immediate bearing on the balance between the three forces. For example, rainfall distribution obviously influences vegetation cover but this is not shown. Nevertheless the picture that is presented remains complex and drives home two important facts:

(i) erosion is the end result of a complex set of interactive forces;

(ii) the interactive forces are in turn the result of complex sets of interacting variables.

In the diagram (Fig.7) each box represents a variable whose value depends upon local environmental circumstances and which contributes in some greater or lesser degree to the overall erosion hazard. If the value of the variable errs to the left of the scale (e.g. LOW raindrop energy), erosion hazard is for that variable less. Conversely, if the value tends to the right, hazard is high. The erosion that finally results will be the net effect of the values of the variables in each box in the systems diagram.

How could such a diagram be used in environmental education? There are a variety of ways depending upon educational level. At its simplest the balance between the core elements of energy, protective and resistive forces can be discussed. Erosion is a work process requiring energy to overcome a resistance. The applied energy available to overcome the resistance is screened by protective forces. If E is the sum of the energy forces, R the sum of the resistive forces and P the sum of the protective forces, erosion will occur if $E > R$. But part of the natural energy forces may be reduced by protective forces such that erosion will only happen if: $E - P > R$. The object of soil conservation is to make P and R so large that: $P + R > E$ and no erosion will result.

A pebble on a rough inclined board, simulating a soil particle on a sloping field, serves to demonstrate simply the operation of the three forces. What will make the 'soil particle' move? In other words what

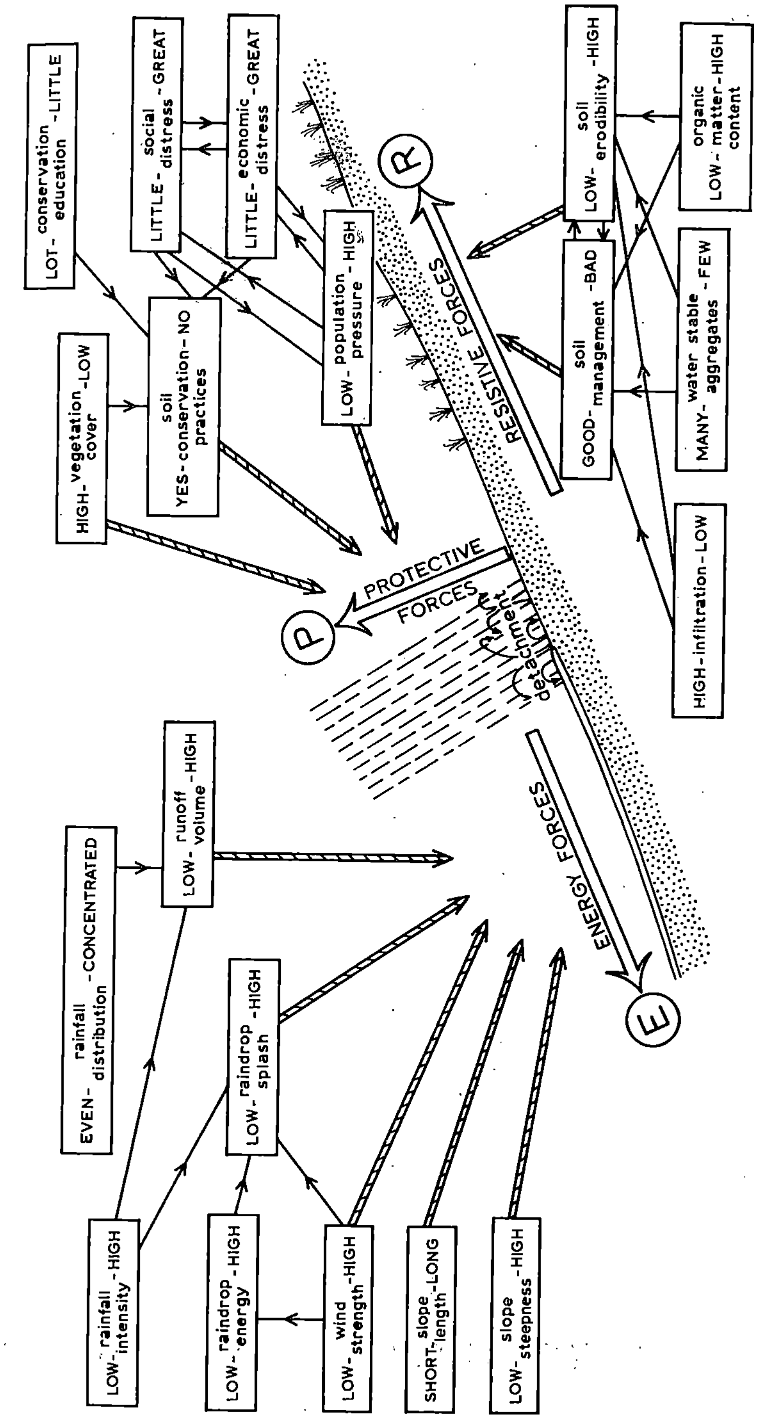

Figure 7 A systems diagram of some of the interactions in the process of erosion

will make energy forces overcome the resistive forces of friction between pebble and board? Naturally, tipping the board to represent a soil particle on a steep field will cause the pebble to move. Other ways would be substituting a smoother board, or rolling another pebble onto the first, or pouring water down the board. The protective forces can be simulated by, for example, substituting a series of steps instead of the board (i.e. contoured bench terraces), or reducing the impact of the rolling pebble, or placing a series of obstacles (twigs, grass) to catch the pebble and stop it rolling any further.

At a more advanced level various combinations of values of the individual variables in the systems diagram might be considered. Determine subjectively what the values for your local area might be. Maps of some of the factors in erosion in Zimbabwe have been published by Stocking and Elwell (1973) and they would assist in assessing the relative value of some of the variables.

The final goal is an appreciation of the complexity of the environment, an understanding of the balances that are operative in the environment, and an awareness that environmental degradation can be the result of many combinations of causes. No universal explanation (e.g. ignorance and misuse of the land) can account for degraded landscapes: degradation and erosion are merely the symptoms of environmental stress. And where these symptoms become serious, then they turn full circle to become the causes of more degradation and more erosion (Fig.3). In such a manner, a vicious cycle is constructed in which distress encourages degradation, and degradation brings yet more distress. That perhaps is the most important ecological and environmental interaction to be taught.

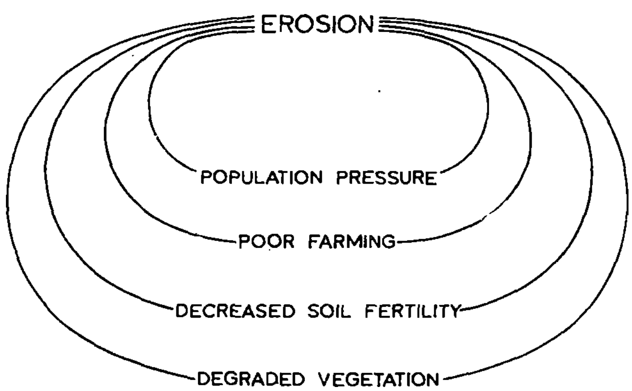

Figure 8 Vicious cycles in erosion

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WHY PRESERVE NATURAL RESOURCES?

The immediate answer to the question 'Why preserve natural resources?' is self-interest. However there are other answers. Less tangible reasons concern notions of the long term preservation of the environment being 'a good thing', thoughts that we are the guardians of our physical heritage and must maintain it for future generations, and ideas of landscape aesthetics and the beauty of nature.

These notions are essentially cultural products of society and they develop with an appreciation of one's surroundings. In societies reliant upon a direct relationship between man and nature (e.g. hunter-gatherers, or subsistence farmers), the notions manifest themselves in poetry and oral literature, and traditions develop which effectively preserve natural resources. While soil degradation has featured throughout history and can even partially account for the collapse of some civilizations (e.g. Mayan of Central America, the ancient civilizations centred around the Tigris and Euphrates) most societies have developed practical methods of conservation. In Africa, multicropping and intercropping - the mixed planting of different crops on the same plot at the same time - has many advantages. Not only does it protect from risk of crop failure, it also provides a better and more continuous protection to the soil, is up to twice as efficient as monoculture in the conversion of solar radiant energy into usable calories of food, and it minimises the area to be cleared for agriculture.

In Western ideology the notion develops rather differently. It is manifest in the resurgence of 'ecological movements' especially in France and Germany whose concern rests not so much with a direct interest in and reliance upon the environment (for the roots of the movement are dominantly white, urban, middleclass) but with radical protest in the increasing drift to material values, capitalist production, technology and the wasteful depletion of natural resources. The point to note is not that these notions exist but that we all of us have an innate cultural bias towards the preservation of resources. It is debateable, therefore, whether or not they can be taught formally. However, the threat to our cultural controls upon environmental degradation are from such things as anti-social practices (e.g. cultivation of steep mountain slopes causing floods and sedimentation on the plains below), short-term self-interest (e.g. overgrazing) or economic and political subjugation (e.g. patterns of land tenure fixed for national or local reasons). The reinstatement of the natural inclination of society to preserve resources most therefore stem from the very threat, and appeal to self-interest and the improvement of personal and communal living standards.

Pragmatically, then self-interest is the key to education in the concepts of resource management, allocation and use. The educator should seek the immediate benefits of preserving the environment. With an appreciation of these benefits, only then is it advisable to look to deeper, cultural answers to the question 'Why preserve natural resources'.

Soil erosion is an ideal subject for demonstrating the benefits of conservation. Consider first the human consequences of soil erosion. Table 1 indicates a possible sequence in a scenario of soil erosion that stems from an initial population increase taking the total population above the safe carrying capacity of the land:

This is only an example of one possible sequence. Others could be imagined where, for example, the severe social disruption leads to a short-term political solution such as land redistribution. It would be instructive to ponder on whether possible solutions to the inexorable decline to starvation do anything other than postpone slightly the progression in the sequence.

Where does soil conservation fit into the scenario? A dispassionate analysis of where exactly your local area is in the sequence would be interesting. It may be that your area displays partial evidence of several steps in the sequence simultaneously. What are the solutions? Clearly conservation is most appropriate at the very first steps in reducing the rate of decrease of soil fertility and controlling the rate of population increase. At any other step conservation can only tinker with a system that is already spiralling out of control. Nevertheless many of the steps are reversible. If the initial problems of decline of fertility and increase of population can be halted then political organization could, for example, help solve problems of land competition, or scientific advances in range management can help to halt the degradation of grasslands and reduce grazing pressures. Good conservation is not then a piecemeal input of resources by such measures as better farm management. It should be a frontal approach at every link in the chain, but especially at the first.

Discussion and explanation of these sorts of issues can help gain appreciation of our immediate self-interest in preserving resources and in the long-term a feeling and understanding for the environment.

TABLE 1

declining soil fertility: the fertile fraction of the soil rests in the main in the finer particles of soil (silt, clay organic matter); these are the first to be removed by erosion.

declining crop and grassland productivity: with the fertility reduced the supply of nutrients to the plant is reduced.

A. CHANGES IN LAND USE

increasing area of cultivated land: reduced crop yields force farmers to cultivate more land.

increasing area of grazing land: reduced grassland productivity necessitates a greater area of grassland per animal

B. LAND COMPETITION

overcropping: intensive production methods cause further decrease in fertility.

overgrazing: cattle numbers fixed for social and economic reasons. Palatable and nutritive grass species eaten out.

degradation of arable lands: poor vegetation cover provides little protection from erosion.

degradation of grassland: palatable species replaced by discontinuous cover of woody shrubs; more erosion results.

crop failures: excessive runoff and lack of soil fertility cause crop failure in a season of low rainfall.

cattle deaths: cattle in poor condition and eventually die in a season of low rainfall.

C. SEVERE SOCIAL DISRUPTION

reliance upon imported food
dissatisfaction with allotted amount of land
breakdown of society and kinship bonds
rivalry and war
disruption of lines of supply for food
starvation

WHAT PRACTICAL METHODS CAN HELP HALT DETERIORATION?

The discussion so far has been aimed at building an appreciation for the environment and a want to preserve it. These ideas are prerequisites for the final step in motivating a person to carry out practical methods in conserving the environment.

Again soil erosion provides a ready means for demonstrating reversals in its process and for school projects aimed at rehabilitating eroded areas. In order to succeed, environmental education cannot merely be the establishment of a body of theory: it must be shown to work. Bearing in mind that the maintenance of soil fertility is a key to conservation, one simple and direct experiment is to compare the yields of a maize crop on adjacent small plots. One plot may have been producing crops for some time and have had no inputs of fertiliser or manure; the other plot will be thoroughly composted before planting. Comparative data for the two plots can be recorded as in Figure 9. It could be calculated how many of each type of plot would be required to feed a family for a year. The difference in growth patterns between Plots A and B would allow a greater proportion of the energy of falling rain to strike bare ground and cause detachment. The difference in yields indicate that the fertility status of the two soils differ and that other things being equal a poor soil promotes more erosion than a good one.

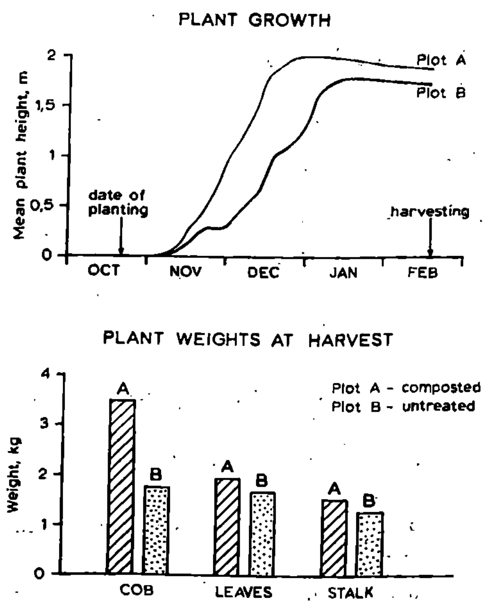

Figure 9: Comparative data on a simple plot experiment

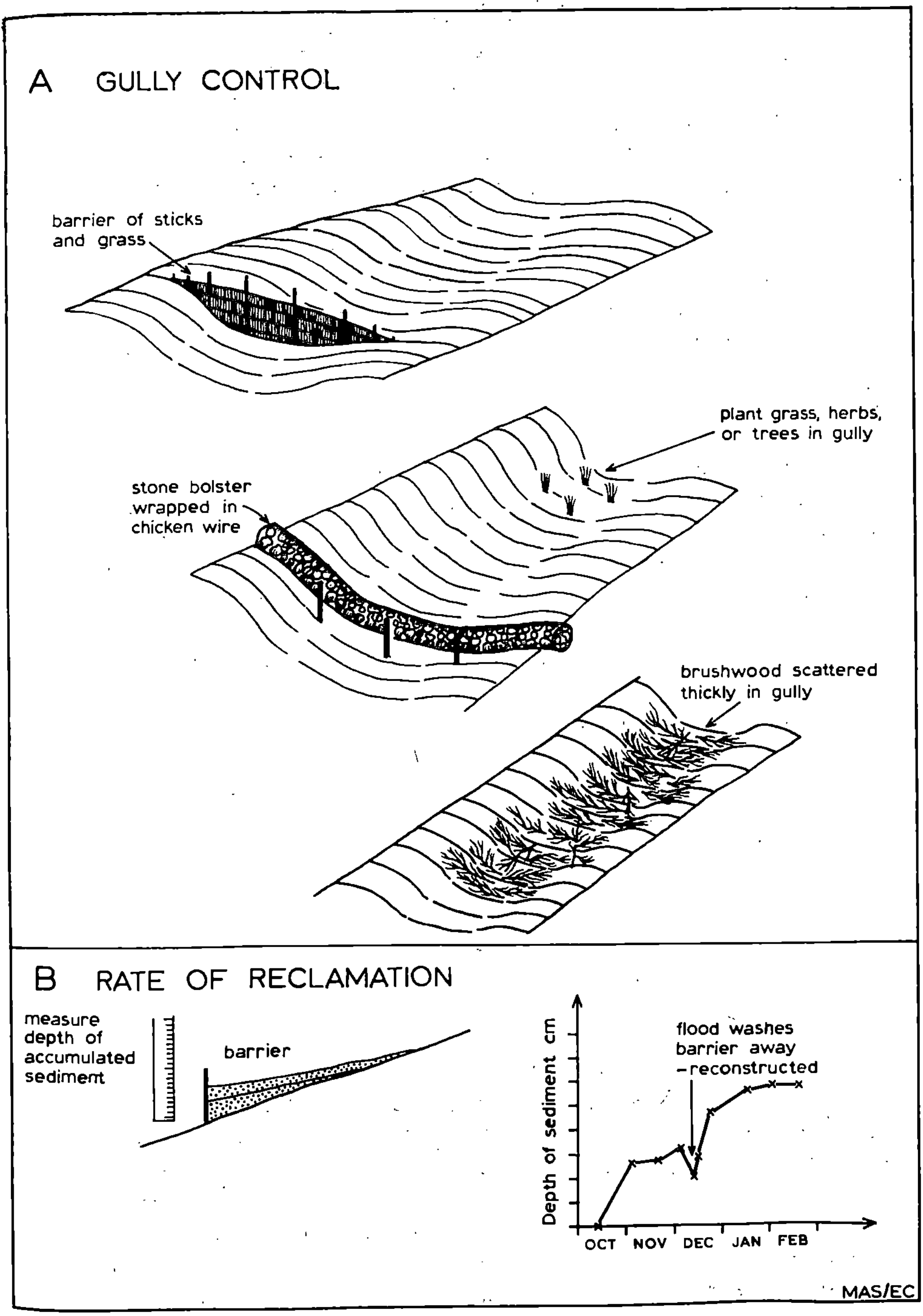

Figure 10 Simple methods of Promoting gully sedimentation

Educational projects can also utilise gullies. If it is considered that a gully is merely a channel along which water and sediment travels, a means of retarding the flow of water would encourage it to drop its load of sediment and the gully would gradually infill. The most obvious way of doing this is to construct a porous barrier across the gully so that the water can pass through slowly but leave its load of sediment. The accumulation of sediment will in turn reduce the gradient of the floor of the gully and further encourage the water to drop its load. Barriers of sticks and grass are sometimes used, but they are often swept away in the exceptionally heavy storm. More substantial barriers of stones wrapped in chicken wire are common (Fig. 10A). Other methods include the placing of brushwood along the gully to trap sediment and planting grass, sisal or even trees in the base of the gully. Indeed tree-planting to rehabilitate gullies is a common practice in Swaziland where the local community maintains the plantation as a source of fuel wood and building material. Again this illustrates the incidental but nonetheless direct benefits that conservation can bring if planned with a feeling for the needs of the community. The catchment to the gully must also be a focus for concern because it is here that runoff waters concentrate.

The best way to minimise this build-up of water is to control grazing and land use pressures in the catchment to allow grass to regenerate and consequently promote the better infiltration of water.

Gully control can be exceedingly frustrating. Structures built by conservation engineers are often washed away and destroyed. However, it is possible to heal many smaller gullies with the simple methods outlined in Figure 10 especially if this is co-ordinated with improvements in the catchment to the gully. Finally, it is valuable to monitor the rate at which sedimentation is occurring. This is best achieved by measuring the depth of accumulated sediment next to the barrier (Fig. 10B).

CONCLUSION

Environmental education is being increasingly stressed because of the obvious degradation of the environment all around us. It finds a place in curricula for geography, biology and agriculture courses where it is imperative that students find interesting and absorbing experiments and projects to undertake. I hope that this article may provide a few ideas for teachers on practicable field work, as well as giving a useful conceptual framework around which to build an appreciation for the environment. Comments and feedback on the success or otherwise of these and other exercises in environmental education would be most appreciated by the author.

ACKNOWLEDGEMENT

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