MEMP Phase I
Final Report

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I. Introduction

The United Sates Agency for International Development [USAID] and the government of Malawi (GoM) are collaborating to provide the Malawi Environmental Monitoring Program [MEMP] with the necessary field, technical, and analytical training to carry out several environmental monitoring activities. MEMP was initiated to fulfill a threefold mission aimed at assisting the Ministry of Research and Environmental Affairs [MoREA] and other departments to:

1. Monitor the environmental impacts of policy reforms, in particular the impacts of smallholders' production of burley tobacco;
2. Establish a national capability to assess, monitor, and manage the environmental resources of Malawi; and
3. Provide equipment, training, and methods necessary for the fast and efficient production of maps, documents, and reports based on the results of MEMP's environmental monitoring activities.

II. Statement of Purpose and Rationale

The purpose of the MEMP is to support the GoM's Ministry of Research and Environmental Affairs (MoREA) and technical line agencies in the design and implementation of a national environmental monitoring system. The MEMP was initiated in 1993 to monitor the environmental impacts of Agricultural Sector Assistance Program (ASAP) policy reforms and, particularly, to assess the environmental impacts that might accompany an increase in the number of smallholders involved in the production of burley tobacco. Expansion of the ASAP in 1994 has greatly expanded the scope of the agricultural and natural resource management policy reform agendas, requiring an expansion of MEMP activities so as to monitor concomitant environmental impacts.

The objectives of the first two years of the MEMP are to strengthen the technical and institutional capacities of DREA [MoREA] and line agencies in order to (a) assess the possible environmental impacts of smallholder burley tobacco production; and (b) build a broader technical capacity within line agencies upon which a viable national Environmental Information System (EIS) can be based.

III. Design Strategy

A. Decentralized Structure

Rather than develop an autonomous capacity for environmental monitoring in MoREA that could result in long-term dependency on donor support, MEMP has sought to engage and build upon the existing capabilities of line ministries. The agencies included initially are the Land Resources and Conservation Branch (LR&CB) of the Ministry of Agricultural and Livestock Development (MoA&LD), the Ministry of Irrigation and Water Development (MoI&WD), the Department of

Forestry in the Ministry of Natural Resources, the Meteorology Department, and the Department of Surveys.

B. Capacity Building

MoREA is seeking to clarify its vision of a cogent approach to environmental management. As a coordinating agency, it may find that development of an improved administrative capacity is sufficient. However, a serious constraint to improved environmental monitoring is the shortage of appropriate technical and managerial skills. Both of these areas are being addressed as part of the UNDP's Institutional Support for Environmental Management (ISEM) program in the Environmental Affairs Department.

During the first two years of implementation, the MEMP focused more on refining technical skills (e.g., spatial analysis tools such as Geographic Information Systems [GIS]) than in developing its administrative skills within MoREA.

Training in GIS technical skills has revealed three facts: (1) Even within this single area, in-service training cannot satisfy need. (2) The focus on GIS training highlighted the shortage of personnel broadly trained in the environmental sciences. (3) GIS training has not included modules in which trainees are taught to assess or use data. Consequently, there is very little capacity within Malawi to perform applied research on environmental problems. In the future, MEMP must have a **more diversified approach** to build capacity in the arenas of training *and* applied research in the environmental sciences.

1. Design and Reporting

A technical review workshop of MEMP in April 1995 listed the following variables as essential to monitor pressures and impacts on the environment: changes in agricultural land use, nutrient loss, soil loss, water quality, and wood consumption. The MEMP has received some of these data, but significant data gaps remain. By February 8, 1996, sampling data for one watershed (time series data from January 1995 to April 1995) on water quality, soil and nutrient loss, and rainfall have been processed and entered into a spreadsheet. Some of the data for other catchments have been obtained, but have not yet been incorporated into the database. No data on changes in agricultural production, land use, and wood consumption have been received, and soil specialists still have to process some of their field data. Other, more general data, for example the number of households located in the watershed and their economic and social characteristics, have not yet been compiled, but would provide contextual information for the analysis and allow additional comparisons between the four watersheds.

The MEMP has encountered various problems in obtaining and compiling these data, resulting primarily from the collaborative nature of the monitoring program. MEMP staff reported delays in obtaining some of the data sets (requested in July 1995 and delivered in December 1995). Possible explanations for this delay include lack of commitment from collaborating agencies, change in priorities, limited human resources, and overall government shutdowns. Many times, collaborating agencies provided data that were not fully analyzed or of little use (too much detail, for example) by generalists in the MEMP unit. These obstacles may have resulted either from (1) a lack of clear specifications and misunderstandings on the specific data needs for the MEMP, or (2) a lack of the capability to analyze the field data, whether in line agencies or the MEMP itself.

Using existing data for one watershed, the MEMP has prepared two draft reports, one a synoptic Environmental Data Report Summary and the other a more detailed Environmental Monitoring Report. The World Resources Institute reviewed the purpose, outline, analysis, and data presentation of these reports, and arrived at the following conclusions.

While MEMP staff had identified different audiences for these two draft reports, decisionmakers and technical staff respectively, the authors ultimately dissipated some of their intended focus. For example, the Environmental Data Report presented field measurements (times series of sediment discharge, nutrient, and pesticide concentrations) and discussed constraints and proposed solutions related to the implementation of the MEMP. Similarly, the Environmental Monitoring Report became a combination of a technical description of the monitoring program (sampling sites, data collection, process of collaboration among line agencies, etc.) as well as an analysis and presentation of results of selected data for the 1994/95 monitoring season. Such an approach provided important information, but left the reader looking for an answer as to whether changes in land use, i.e. increased growing of burley tobacco, have affected the environment.

2. Environmental Monitoring Technology

Geographic information technologies, such as GIS, Remote Sensing, and Global Positioning Systems (GPS) are computer-assisted tools for the collection, storage, analysis and display of environmental phenomena. These tools, collectively, offer the potential for a higher degree of access to geographic information for the efficient and effective management and analysis of spatiotemporal data (e.g., the data collected during environmental monitoring) while maintaining greater precision than previously-used methods. Ultimately, the use of these technologies can provide environmental decisionmakers with more timely and accurate information, and can therefore contribute to a more explicitly reasoned decisionmaking process.

Although the use of these technologies shows significant promise for environmental management, it must be recognized that they have not met with the expected success rate in development settings. GIS has been demonstrated and used successfully at the project level, but long-term sustainable implementation of this technology has been rare. In part, this can be attributed to a number of technological issues such as effective training in the use of highly technical software, accessible user interfaces, stable computing environments, access to data networks, etc. However, while these are important issues, to which significant resources are being directed, the more substantive problems related to sustainable technology transfer are associated with organizational and social issues.

The goal of the technology transfer component of the MEMP is to allow the participating agencies, in a coordinated fashion, to employ new geographic technologies to analyze data and provide environmental information in contribution to the program, and in the long-term, provide the important elements for a broader based national-level environmental information system. Toward attaining this goal, microcomputerized equipment, procured in the U.S. but serviceable in Malawi, was purchased. The list of equipment includes microcomputers suitable for GIS and Remote Sensing, data collection and acquisition instruments such as digitizing tablets, tape drives, and GPS units, GIS and Image Processing software to manipulate these data, and peripherals such as printers.

3. Participatory Techniques

a. Participatory environmental monitoring

To fulfill its objectives, MEMP has been conducting monitoring programs in five small catchments near the towns of Nkhata Bay, Chikwawa, Ntcheu, Mangochi, and Kasungu. The monitoring activities include water sampling at catchment outlets, installation of erosion control-plots and pits, field monitoring pits, and the installation of automated samplers at two of the above-mentioned locations.

Whereas the control plots were managed by MEMP staff who were trained in soil conservation practices, the field pits were managed by the local farmers themselves. Each farmer was also responsible for both reporting the runoff measurements and for collecting the water and sediment samples for subsequent analysis by MEMP staff. All farmers, field assistants, and District Office staff involved in the MEMP received theoretical and some practical training prior to the last monitoring season. In some cases, farmers themselves organized committees for overseeing data collection activities.

b. Participatory research

A survey was conducted in four catchments, Njolomole, Kamundi, Chilindamaji, and Chulu, where MoREA has been collecting rainfall, sedimentation, and runoff data since August 1993. The survey team stayed eight days in each catchment meeting with elders, focus groups of men and women, and with individual farmers. The survey was designed to ascertain farmers' perceptions, assumptions, and decisionmaking processes that impact natural resource use.

Results of the survey indicate that farmers are particularly aware of changes in natural resources as they affect farm productivity and profitability. The gradual contraction of rainfall and thinning forest cover is associated with declining crop yields and time to find fuel and building materials respectively. Farmers across catchments use similar measures to describe changes but the indicator species or parameter may vary depending on the agroecological zone. For example weed species indicating changes in soil fertility differed between catchments as did pest and disease changes in response to declining rainfall. Agricultural intensification is apparent where population pressures are highest in the south and central regions. Intensification is apparent with decreasing fallow and rotations, and an increase in intercropping.

Farmers listed their major concerns as the cost and availability of inputs followed by lack of safe drinking water and adequately equipped medical facilities. In addition, farmers' efforts to implement conservation practices are hampered by lack of knowledge, poor health, lack of food, and overburdened extension agents who are vested in delivering programs rather than being responsive to farmers' needs. Farmers are slow to acknowledge or unaware of their own actions in creating unfavorable resource changes, and quick to point to the detrimental actions of others. Lack of knowledge or unwillingness to assume responsibility for actions is a serious impediment to (1) farmers' understanding of the rationale for monitoring, and (2) instigating conservation measures.

Involving farmers in an environmental monitoring scheme is probably ambitious at this time. There is no broad-scale understanding of cause and subsequent environmental effect, so presumably few would volunteer for collection of information. Recordkeeping skills are meager

and illiteracy high, limiting collection to the literate; alternatively, oral or pictorial methods for recording change might be devised.

However, understanding farmers perceptions allows planners and policymakers to more effectively design interventions that recognize farmers' realities and sequence measures in a way that makes sense to farmers. Complex factors affect natural resource decisionmaking, and it seems logical to have farmers determine the priorities and processes for their resolution rather than being forced to meet narrow objectives imposed by government or donors.

C. A Flexible and Adaptive Approach

The initial purpose of the MEMP was to assess the environmental impacts that might accompany an increase in the number of smallholders involved in the production of burley tobacco as a result of policy liberalization. Policy liberalization has surpassed original expectations and has affected the agricultural sector as a whole. With the completion of the National Environmental Action Plan (NEAP) and the development of an Environmental Support Program (ESP), Malawi is much more aware of its critical environmental problems. The emphasis of the MEMP has accommodated the increasing concern over issues of land degradation through soil loss, deforestation, and resultant reduced water flows through major river systems.

The original program design was highly focused on technical approaches to detect change in biophysical parameters with little attention paid to socioeconomic factors. This oversight was modified early during implementation, resulting in an approach where direct field measurements of biophysical change attributable to the impact of policy can be correlated to change in socio-economic parameters. As a result, the four remaining catchments now offer considerable baseline data from which other policy impacts can be evaluated.

One difficulty facing the MEMP in its initial phase is that despite policy liberalization, the farmers' hypothesized entry into burley production has not occurred. Probable reasons include the rise in fertilizer prices concomitant with policy liberalization, the inability of the seed distribution infrastructure to respond to the mandates of the crop calendar, the competition of burley nurseries with women's traditional cash-crop lands, and perhaps a widespread consensus among farmers that despite policy liberalization, entry into burley is simply too risky. As a result of this and other problems, the project has been modified considerably from its original design. A broadening scope, combined with the inherent uncertainty about the nature and magnitude of environmental problems confronting Malawi, suggest that an adaptive approach to project design and initiation should be continued.

D. Development of a National Monitoring Capability

For two reasons, the catchment sites developed in the previous eighteen months are not viewed as pilot sites from which to expand the number of sampling areas to cover the entire country. First, the cost of duplicating the effort to gather the baseline information prohibits replicating the effort in anything more than the remaining agroecological or farming-system zones in the country. Second, continuation of this effort cannot be justified until further agency commitment is demonstrated. In light of this, the catchments are viewed as specific sites from which to intensively gather environmental data that can be compared to similar areas found in larger

administrative units such as the EPAs, RDPs or ADDs. The result will be two levels of monitoring: (1) site-specific intensive data collection, and (2) extensive monitoring areas. Linkages between the two data levels will be accomplished through appropriate monitoring technologies, such as GIS. Training, development, and institutionalization of appropriate technologies, initiated during the past eighteen months, must therefore continue.

IV. Investigations

A. Participants

Modifications to the MEMP's original design resulted in a program where individual rainfall events are summarized by duration and intensity while accounting for microscale variation across the catchments. These data are compared with the automated sampler measurements made by the Department of Meteorology. The water and sediment runoff measurements of each individual rainfall event were collected by farmers and field assistants from field pits. The field pits were selected on a basis of slope, soil type, and crop cover. Data from the pits are compared with data collected by EPA staff on control plots located in EPAs. Information pertaining to the influence of different farm practices on the runoff sample results was gathered by LR&CB field assistants. Analyses of the soil data were made by the two soils laboratories run by the Ministry of Agriculture and Livestock Development. Aggregated stage and flow data from the entire catchment were monitored by the Department of Water, with analysis of water quality provided by their Central Water Laboratory. Analysis for organophosphate pesticides was undertaken by the Malawi Bureau of Standards.

The Forestry Research Institute of Malawi (FRIM) in conjunction with the Department of Forestry is collecting household information on wood consumption by species and use. Permanent Sample Plots are located in the catchments and monitored for change over time. HIID completed the socioeconomic baseline study in August, 1995, for all catchments but Chikwawa.

B. The Environmental Effects of Smallholder Burley Production

Table 1 below lists the data both collected by and made available to the MEMP.

Table 1. Data Collected By and Made Available To MEMP

BASELINE DATA	Chilindamaji (Nkhata Bay)	Chulu (Kasungu)	Njolomole (Ntcheu)	Kamundi (Mangochi)	Kalambo (Chapananga)
IMAGERY					
Air Photo	1990 - 1:25K 1993 - 1:10K	1990 - 1:25K (partial park coverage) 1993 - 1:10K	1990 - 1:40K 1990 - 1:10K 1993 - 1:10K	1990 - 1:40K 1993 - 1:10K	1990 - 1:40K 1993 - 1:10K
Satellite	9/72 - MSS 9-10/91 - TM 87-94 - NDVI	9/72 - MSS 9-10/91 - TM 3-4/94 - SPOT 87-94 - NDVI	9/72 - MSS 9-10/91 - TM 6/92 - SPOT 87-94 - NDVI	9/72 - MSS 9/81 - MSS 9-10/91 - TM 3/95 - SPOT 87-94 - NDVI	9/72 - MSS 9-10/91 - TM 87-94 - NDVI
Video			1994 - 1:?K	1994 - 1:?K Video Mosaic	1994 - 1:?K
MAPS (D)=digital					
Topography	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K
Landuse	1994 - 1:5K (D)	1994 - 1:5K	1994 - 1:5K (D)	1994 - 1:5K (D)	
Hydrography	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	
Boundary & Road network	1994 - 1:5K (D)	1994 - 1:5K	1994 - 1:5K (D)	1994 - 1:5K (D)	
Soils	1994 - 1:5K (D)				1994 - 1:5K
Forest Cover	1994 - 1:5K (D)	1994 - 1:5K		1994 - 1:5K (D)	
Slope / Erosion Hazards	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	
Microshed Analysis		1994 - 1:5K (D)	1994 - 1:5K (D)	1994 - 1:5K (D)	
WATER					
Guaging	Manual	Automatic	Manual	Automatic	
Control plots	3	3	3	6 - Includes 3 agroforestry trials	3 - 1994/95 only
Field pits	4	6	4	6	5 - 1994-95 only
Shallow wells	Water level too deep	2 - 1995/96	2 - 1995/96	1 - 1995/96	
RAINFALL					
Automated	1	1	1	1	1994-95 only
Standard	6	6	6	6	1994-95 only
SOCIO-ECONOMIC					
Source of income	1995	1995	1995	1995	
Wealth ranking	1995	1995	1995	1995	
Food security	1995	1995	1995	1995	
Source of land	1995	1995	1995	1995	
Reason for fallow	1995	1995	1995	1995	
FORESTRY					
Forest products used by species	1995	1995	1995	1995	
Stems per hectare	1995	1995		1995	
Diameter classes	1995	1995		1995	

continued

Table 1 (continued)

DATA INPUT	Chilindamaji (Nkhata Bay)	Chulu (Kasungu)	Njolomole (Ntcheu)	Kamundi (Mangochi)	Kalambo (Chapananga)
Water quality	1994/95	1994/95	1994/95	1994/95	
Water flow	1994/95	1994/95	1994/95	1994/95	
Rainfall	1994/95	1994/95	1994/95	1994/95	1994/95
Agronomic	1994/95	1994/95 (gaps)	1994/95 (gaps)	1994/95 (gaps)	1994/95 (gaps)
Sediment	1994/95	1994/95 (gaps)	1994/95 (gaps)	1994/95 (gaps)	1994/95 (gaps)
Pesticides	1994/95				
ANALYSIS & REPORTING	**Chilindamaji (Nkhata Bay)**	**Chulu (Kasungu)**	**Njolomole (Ntcheu)**	**Kamundi (Mangochi)**	**Kalambo (Chapananga)**
Water quality	1994/95				
Water flow	1994/95				
Rainfall	1994/95				
Agronomic	1994/95				
Sediment	1994/95 (USDA)				
Pesticides	1994/95 (MEMP)				

1. The Socioeconomic Baseline Study

This survey enumerated a broad range of socioeconomic conditions in smallholder households who farmed fields (either burley tobacco or other crops) in the MEMP catchment areas. The purpose of the survey was threefold: (1) to collect basic household data to facilitate analysis of how burley tobacco production among smallholder farmers is affecting household economic conditions; (2) to ascertain the effect on broader socioeconomic conditions of the adoption of burley production among smallholders; and (3) to derive the consequences of burley production on natural resources.

The present analysis focuses on patterns of agricultural production, relative wealth of burley growers, food security, land acquisition and fallowing, and use of forest products. Overall, the findings in this survey appear to confirm previous assessments of the relationships between burley production and smallholder wealth, food security, and resource management. In general, burley growers tend to be the wealthier smallholders who are more secure in their food supplies, and who are least likely to face serious problems of resource scarcity. The survey does not reveal major recent changes in overall patterns of agricultural production, although many previous burley growers appear to have stopped this year, mainly due to problems related to shortages of fertilizer. Moreover, the survey appears to suggest that overall patterns of land acquisition are similar between burley and non-burley households, although there appears to be a positive association between greater wealth and acquisition of land through the husband's family. Although patterns of acquisition are generally similar, patterns of land use do appear to differ, with burley growers typically leaving less land fallow than non-burley households. Burley growers also have a particularly high demand for certain wood products, especially poles for constructing tobacco drying sheds.

a. Patterns of agricultural production

Most smallholder farmers in Malawi, including burley growers, pursue a strategy of diversified agricultural production, which includes combinations of hybrid and local maize, cassava, sunflower, legumes, vegetables, fruits, and tobacco. Most of these crops can be used for both home consumption and for cash sales. The impact of burley production on smallholder household

economics must be considered in light of ongoing efforts by smallholders to maintain diversified production. None of the smallholder burley growers in the MEMP survey engage solely in burley production, and most allocate only a portion of their available land and capital to burley production. Similarly, even among burley growers, burley represents only one among a number of strategies for generating income. There is no clear evidence of a shift toward increased allocation of resources to burley production. Although more research is needed, there is some evidence of decreasing interest in burley production, particularly as a result of recent steep increases in fertilizer prices.

The relative importance of burley also appears to vary across catchments. In three of the four catchments, burley was reported as the primary source of cash income among burley growers.

It is important to stress that even among burley growers, while burley is the most important source of cash income it is not necessarily their main source of livelihood (Figure 1). All burley growers in the MEMP sample also grew maize (or, in Nkhata Bay, cassava) as a food staple, as well as combinations of legumes, tubers, vegetables and fruits.

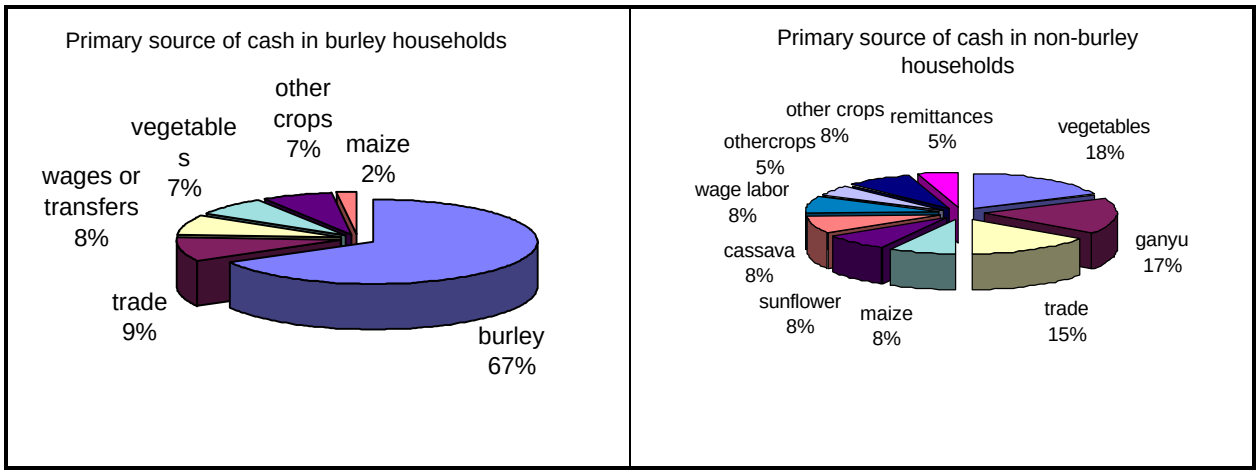

Figure 1. Primary sources of cash income in burley and non-burley growing households.

b. Indications of change in burley production

There is little evidence from the MEMP catchments that a large number of smallholders are shifting into burley production, and there are reasons to believe that under present conditions of increasing fertilizer prices and the collapse and abuse of some burley clubs, the number of smallholder burley growers is unlikely to expand significantly. The MEMP socioeconomic survey recorded a number of non-burley growers who had previously grown burley but stopped because of problems related to credit and fertilizer.

The reasons for failure in burley growing mainly involve problems with fertilizer and credit, although poor rains have also played a part. Smallholders complained that burley clubs (which are intended to provide credit for inputs, particularly fertilizer) had collapsed due to nonpayment of debts and because of disputes over the distribution of profits from sales at auction floors. At the Njolomole site, these problems were recorded in 1994, and continue to represent a significant barrier to participation in burley production. At the Chulu site, a very large number of farmers who were identified as having started burley nurseries in the Fall 1994 planting season ended up

harvesting no burley at all because of the failure of local clubs to provide fertilizer on acceptable terms. The number of farmers who attempted but failed in their efforts to grow burley in the Chulu catchment possibly exceeds the number who succeeded. In all catchments, people also complained about unpredictable rainfall. In addition, the recent removal of fertilizer subsidies has put purchases of fertilizer beyond the reach of even relatively wealthy smallholders. Despite these problems, smallholder interest in burley production remains high, especially following the relatively good prices of the last season. But without improved access to credit and/or lower fertilizer prices, the number of smallholders growing burley is unlikely to grow.

c. The relationship between burley cultivation and smallholder wealth

Smallholder farmers who grow burley are, on the whole, wealthier than non-burley-growers. This relationship is demonstrated by the predominance of non-burley households (70 percent) in the lowest wealth quartile, whereas most of the wealthiest smallholders (63 percent) are burley growers. In the mid-level wealth quartiles, households are equally likely to be burley or non-burley growers. Thus, while burley cultivation is not always associated with greater wealth, there is a clear and statistically significant tendency for burley production to be associated with relative affluence among smallholders. The finding that wealth is statistically related to burley cultivation is not surprising, since considerable qualitative evidence exists indicating that burley growers are generally among the wealthiest of smallholder farmers.

Qualitative assessment, from both the MEMP socioeconomic survey and from other socio-economic analyses, suggests that the following interpretations may hold. For the most part, the poorest smallholders are unable or unwilling to invest substantial resources in the potentially lucrative but risky practice of burley cultivation. There is some evidence (particularly in the Chulu and Njolomole catchments) that considerable numbers of poorer smallholders actually were made worse off by investing in failed burley production. However, among those who succeeded in growing burley, many attribute their improved economic condition to burley. Thus, it would appear that in general, smallholders in the middle and upper economic quartiles are most likely to grow burley and that some portion of these find that burley has contributed to increased wealth.

d. Food security

Burley production does not appear to be strongly related to household food production. Overall, households in the MEMP sample annually produced an average of 249 kilograms per capita of their own maize. Burley-cultivating households grew slightly more maize than non-burley households, though this difference is not statistically significant.

Subsistence maize production, however, is not synonymous with food security. Smallholders also buy and sell maize. Because of their greater income, burley producers are presumed to be in a better position to buy maize. In both the 1994-95 and 1995-96 seasons, burley-growing households reported that they ran out or expected to run out of their own-produced maize later in the season (Figure 2), and a higher proportion of burley households reported having purchased or anticipated purchasing maize, reflecting their greater disposable income.

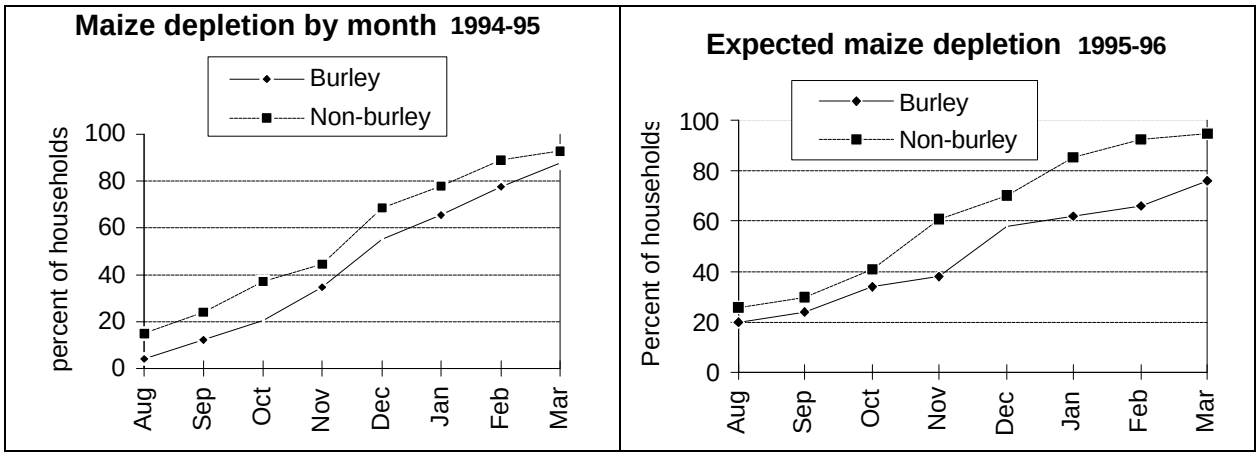

Figure 2. Maize depletion and expected depletion by month in burley and non-burley growing households, 1994-96.

e. Fallow fields

One somewhat surprising finding of the MEMP socioeconomic survey is that a substantial number of fields held by smallholder households are left fallow – 45 out of 273 total fields in the survey, or 16 percent. Without having area calculations for these fields, it is not possible to assess what proportion of the total cropped area this represents. Nevertheless, the extent of fallowed fields is surprising considering the general scarcity of land in Malawi, particularly in the south. However, the MEMP survey also shows that the primary reasons for leaving land fallow are shortages of labor or money, and ill-health (Figure 3). Only 13 percent of fallowed fields are left fallow for the primary purpose of regenerating soil quality. Some of the other reasons that smallholders reported for leaving fields fallow include the fields being "too big" to cultivate completely, that they are newly acquired, or that their quality is poor. On examination, these factors probably refer to shortages of labor or capital to invest in fully cultivating landholdings.

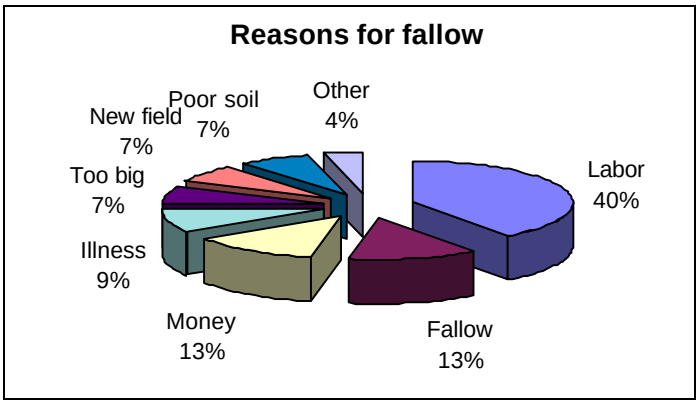

Figure 3. Reasons for allowing fields to remain fallow.

The importance of labor and capital shortages as a reason for fallowing land may explain the general tendency for burley-growers (who are wealthier and therefore in a better position to purchase labor) to leave a somewhat lower proportion of their fields (15 percent) fallow than non-burley growers (19 percent).

f. Forest products utilization inventory

The socioeconomic survey team combined efforts with the Department of Forestry in carrying out the Forest Products Utilization Inventory. This inventory enumerated the main uses of forest products, the preferred species for each type of use, perceptions of scarcity, and actions taken in response to declining availability of forest products.

Respondents were asked to identify the most important products that they obtain from local woodlands in order of priority, and often identified as many as six priority uses. Burley and non-burley households shared very similar priorities, with fuelwood being the overwhelming first priority, and poles being the dominant second priority (Figure 4). Rope, fiber, poles, and timber were the most frequently identified third-priority uses. Other uses identified in each level of priority include hanging racks for tobacco sheds, grass, fruit, medicine, and conservation.

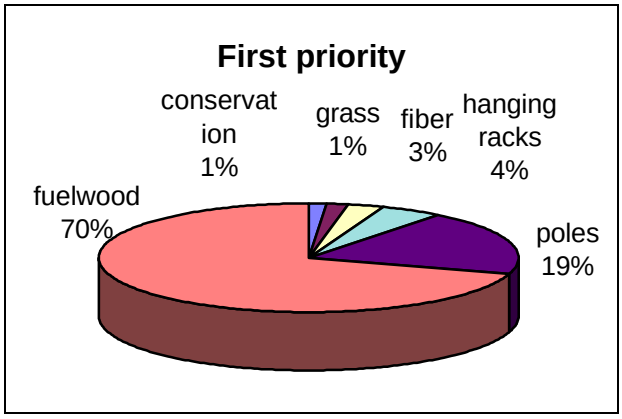

Figure 4. Priority uses of forest products.

The MEMP socioeconomic survey recorded a very large number of preferred species for each type of forest product. In tabulating the total number of "preferred" species for all uses, there are no species that account for more than about 9 percent of the total number of responses. Similarly, for specific wood uses there were no species that were mentioned as being the single most important.

2. The Forestry Inventory

This survey aimed to quantify the woody resource in three catchment areas with remnant woodland cover consisting of native species. The resource was quantified in terms of the number and composition of the woodland species. To complement the qualitative assessment made during the socioeconomic survey, the end uses identified by farmers were quantified . This study enables the MEMP to assess change in woodland cover over time and address the impact of expanded smallholder tobacco production on the tree resources in the catchments. The study was completed by the Department of Forestry and the Forestry Research Institute of Malawi (FRIM). Results are given in Appendix 1 of the Forestry Sample Plot Report, Annex 2 of this document.

3. Soil and Water Monitoring

Comprehensive monitoring of soil and water quality as functions of crop cover and the farming system was undertaken at all catchments but analyzed, interpreted, and reported only for the Chilindamaji catchment. For Chilindamaji, three control plots and four field pits were established.

Two control plots were monocropped with burley and maize, while the third was allowed to lie fallow. Of the four field plots, two were monocropped with burley, two with maize. The three control plots have similar rainfall-runoff relationships, ones characterized by runoff substantially lower than obtained from the field plots, which conclusively demonstrates the effectiveness of erosion-control practices in reducing runoff from fields.

Seven water quality parameters were measured: total dissolved solids, sulfate, nitrate, phosphate, sodium, potassium, and sediment yield. In almost every instance, the field plots released higher amounts of these parameters than did the control plots. Results are tabulated in detail in Annex 4 of this document.

4. Environmental Data

a. Soil loss

One of the objectives for MEMP is to establish and document, with involvement of the farmers at the grassroots level, the on-site and off-site impacts of burley tobacco production on smallholder farmlands.

So far, the results obtained show a positive correlation between the runoff and rainfall events in the burley tobacco control plot as indicated in Figure 5. This was further indicated by high levels of sediment in the runoff following the storm events as highlighted by Figure 6. The high sediment levels indicates major topsoil loss from the farmlands within the catchment.

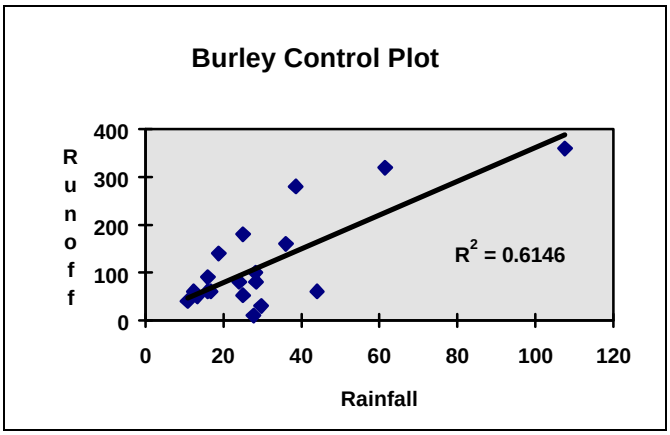

Figure 5. Control plot, Chilindamaji catchment, Nkhata Bay.

The moderate rainfall/runoff relationship (Figure 5) indicates that (1) we can trust farmers to collect valid field data for purposes of environmental monitoring, contrary to the notion that farmers cannot collect environmental data effectively and reliably; (2) the findings from this intensive data sampling can perhaps be extrapolated to other areas of *similar* ecological and rainfall characteristics, hence there is no need to sample every location in Malawi; and (3) there were no notable indicators to suggest that burley tobacco had *significantly* greater effects on soil loss than did other cropping factors. However, considerably more research is required to verify this observation.

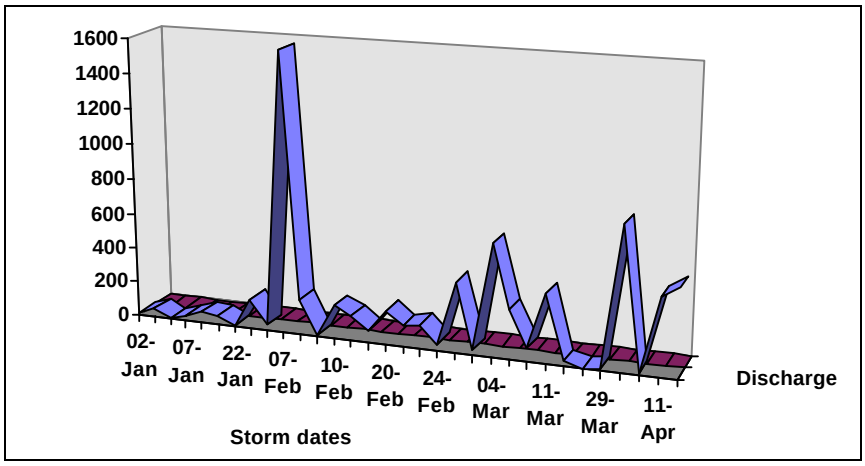

Figure 6. Kalwe River sediment discharge, Nkhata Bay.

b. Nutrient losses

Soil fertility determinant ions are usually concentrated in the finer constituents of topsoil, and thus are easily removed by runoff. Soil loss is accompanied by loss of essential micronutrients. The losses were greater for potassium (K), phosphorus (PO_4), and sodium (Na), hinting at a temporal decline in soil fertility. Nitrate-nitrogen (NO_3) did not show significant presence during the sampling period, most likely due to the use of inorganic fertilizers; usually applied as basal dressing (20:20:0), these contain no water-soluble nitrates. The nutrient losses are indicated by the peaks in the Figure 7 below.

In monetary terms, soil nutrient losses are likely to become translated into a loss of real income and a decline in food security, particularly for the rural resource-poor whose livelihoods depend on subsistence agricultural yields.

c. Water-quality degradation

One of the MEMP's key objectives is to monitor water-quality degradation caused by soil erosion and sedimentation processes, which are themselves functions of farming practices and land use within each catchment. Results of water analyses indicate that erosion processes contributed to sedimentation of stream waters. Analysis of the samples for pesticide pollutants showed positive results for lindane, aldrin, dieldrin, heptachlor, heptachlor epoxide, and DDT (Figures 8 and 9, and Table 2). Levels of these agrochemicals were found to exceed World Health Organization standards for drinking water, indicating a residual water pollution hazard.

Since pesticides can persist in the soil for many years, the residues detected may be associated with pesticide applications of past as well as of the current years. Such residues could exert adverse effects on ecosystems by creating disequilibria in (1) food chains, (2) ecological linkages such as scavengers, parasites, and insect-host relationships, and (3) other biological processes, posing carcinogenic and teratogenic risks to humans.

The persistence of pesticides is a significant finding that requires further research and long-term observation. The issue will be readdressed this year by sampling of groundwater from protected, shallow wells.

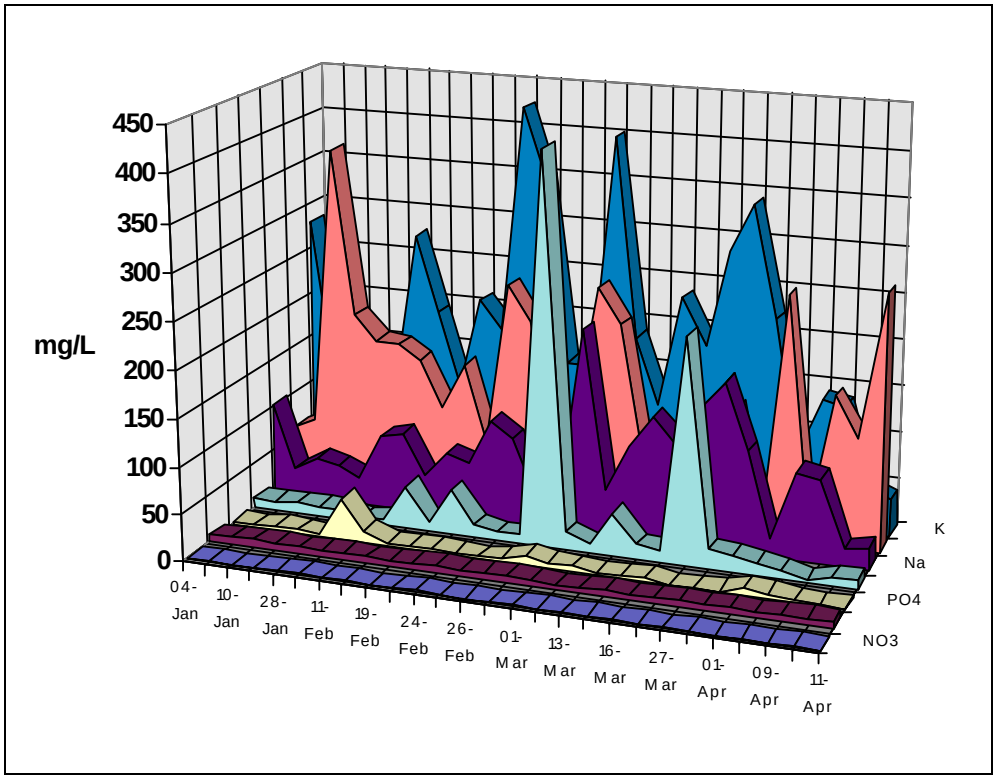

Figure 7. Soil nutrient losses by month in Chilindamaji, Pit 1 (burley).

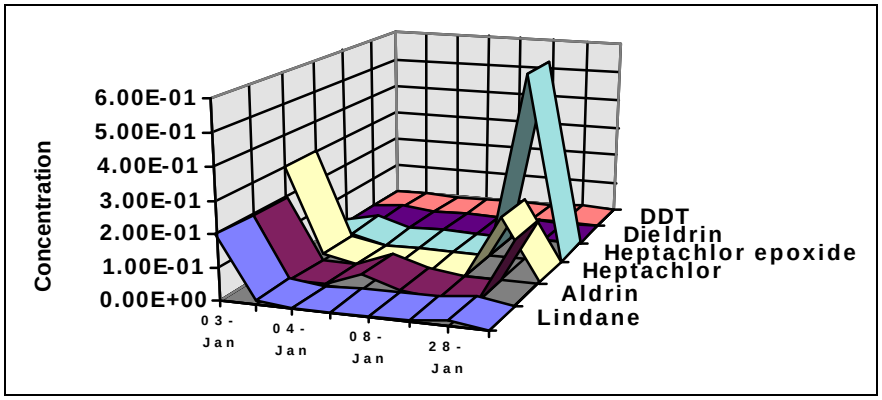

Figure 8. Pesticide variation by date in Kalwe River, Nkhata Bay.

Table 2. High and Low Pesticide Levels Compared with WHO Drinking Water Standards

Pesticide	Lindane	Aldrin	Heptachlor	Heptachlor Epoxide	Dieldrin	DDT
WHO standards	2.00	0.03	0.03	0.03	0.03	2.00
High	200.00	200.00	300.00	10.53	10.00	3.50
Low	0.56	0.39	0.53	0.00	0.00	0.00

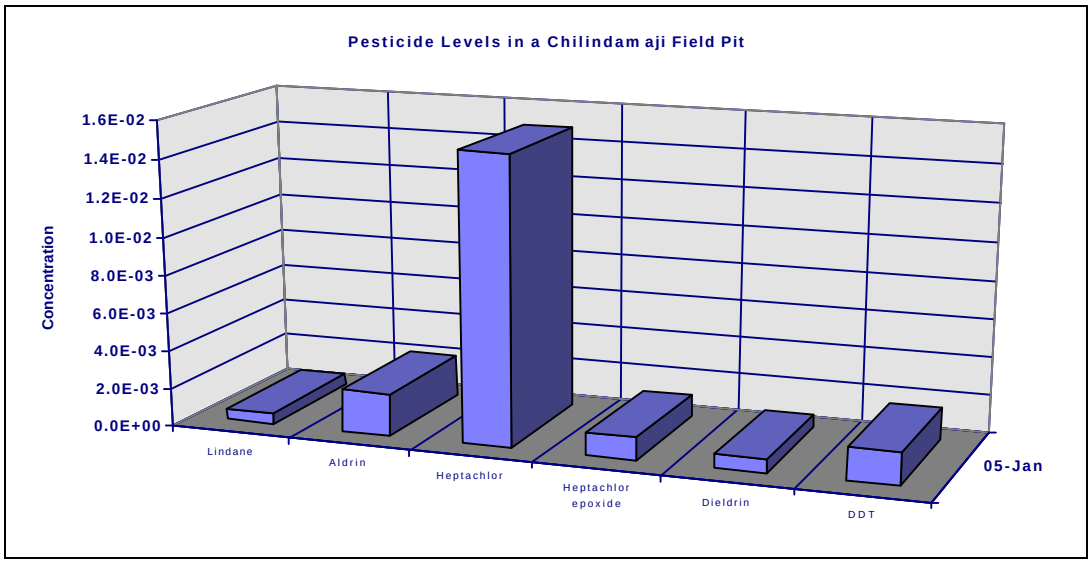

Figure 9. Occurrence of pesticides in a field pit at Chilindamaji, Nkhata Bay.

5. Technology Transfer

The small size of the catchments focuses on the issue of scale in environmental monitoring. During the first phase of the MEMP, participating agencies received training in monitoring possible future climate change over southern Africa with its implications for food security. Examples of monitoring forest resource decline at a national scale were also explored, using NDVI data made available through the Meteorology Department or the Famine Early Warning System. The development of a method to extrapolate environmental data from the catchments to representative regions within Malawi is now necessary. Such a capability will be a major component of MEMP's second phase.

C. Technology Transfer

While each GoM agency involved in the MEMP had specific needs, many were unfamiliar with GIS and the kinds of analytical capabilities required to support the MEMP's monitoring activities. Consequently, an additional set of analytical requirements were deemed to be essential to support MEMP:

- **Multi-Date Change Detection**, in support of monitoring activities. Since many of the data sets were envisaged to be quantitative in nature, procedures for the distinction between true

change and natural variability was a strongly needed component. Similarly, analyses with strong statistical foundations were required.

- **Time Series Analysis**, in support of monitoring activities. Emphasis was placed on the extraction and identification of significant trends.
- **Multi-Criteria/Multi-Objective Decision Analysis** to enhance resource allocation strategies associated with mitigation procedures.
- **Error Analysis and Risk Assessment**. In all contexts there is an important relationship between data quality and decision risk. In developing nations, however, where data resources are limited, this is especially important. Lower-quality data can be effective in decision-making contexts if error levels can be quantified and propagated in analytical procedures. Emphasis was thus needed on simple and cost-effective post-mapping assessment procedures, propagation techniques, and risk assessment procedures.

Given these more general needs, agency-specific requirements identified during this initial stage of the MEMP included the following considerations:

1. Ministry of Research and Environmental Affairs

MoREA constituted a logical demand-point for GIS given that it has been identified as the agency responsible for (1) coordinating MEMP activities, and (2) summarizing and reporting on the results of data products and analyses conducted by the line agencies. In addition to general competency with the use of GIS and related technologies (GPS and Remote Sensing), MoREA staff must be proficient with analytical procedures, particularly in the context of the statistical analysis of spatial phenomena.

2. Department of Forestry

In the context of the burley monitoring project, DoF was charged with monitoring changes in forest resources related to wood use in the burley curing process. As a consequence, emphasis was placed on the use of high-resolution satellite imagery and GIS as a low-cost forest mapping technology. DoF also expressed an interest in the ability to use GIS to help map plantation resources based on surveyors records. Also included were procedures for forest change mapping including change related to both clear-cut and thinning procedures.

3. Land Resources and Conservation Branch, Ministry of Agriculture

LR&CB is the primary agency responsible for landuse mapping in Malawi. In addition, the burley mapping project required that landuse maps be produced for each of the watersheds under study. As a consequence, emphasis was placed in teaching the procedures for supervised and unsupervised landuse/landcover assessment using high-resolution satellite imagery. Special attention was given to ground-truthing procedures using GPS, as well as to post-classification accuracy assessments. Assessment of the ability to detect burley tobacco and distinguish it from other crops was also conducted.

4. Department of Meteorology

For the burley monitoring project, MET was primarily responsible for providing rainfall statistics for each of the watersheds being studied. Emphasis was therefore placed on the interpolation of point data to create precipitation surfaces. This was extended in accordance with more general departmental needs to include the use of Cold Cloud Duration (CCD) data from the Meteosat satellite to act as a predictive component in surface interpolation. Another area of significant interest to MET was the ability to monitor droughts. Thus, specific emphasis was placed on Change and Time Series Analysis techniques associated with the use of NDVI (Normalized Difference Vegetation Index) imagery from the NOAA satellites for the monitoring of El Niño/ Southern Oscillation (ENSO) events. This proved to be timely as an ENSO warm event (associated with drought in Southern Africa) occurred during the 1994-95 summer season.

5. Surveys Department

For most contexts, it was assumed that Surveys would be the provider of topographic data. Thus, emphasis was placed on the development of digital elevation models (DEMs) and the registration of map data to the national geodetic framework. Topics covered included generation of DEMs from digitized contours, generation of DEMs from aerial photographs using PC-based analytical plotter software and image correlation techniques, polynomial-based rubber-sheet resampling techniques, datum adjustments, forward and backward projection, and georeferencing system design. As part of this work, a national level minimum error georeferencing system was designed and subjected to error analysis.

6. Department of Water

DoW was responsible for the siting of stream gauging equipment and the assessment of water quality information. Identified GIS needs included groundwater mapping and nonpoint source pollution assessment. Microcatchment analysis was also covered as part of the process of siting runoff pits. The use of CCD data to estimate rainfall was also of significant interest to this group because of the need to estimate direct recharge into Lake Malawi.

7. Department of Fisheries

DoF was not originally envisaged as a participant in the MEMP, but was later brought into the program because of the importance it plays in regulating Malawi's environment. DoF is primarily responsible for managing the nation's largest natural resource, Lake Malawi. Their main activities are the management of fish habitat and stock, and fishing rights. DoF has found it difficult to maintain an information base on the lake, and it is therefore keenly interested in using automated procedures to facilitate this process.

D. Farmer-Based Environmental Monitoring

The purpose of this component is to develop participatory environmental monitoring methods for assessing change as experienced by local communities. The information obtained from this exercise could (1) assist participatory approaches to sustainable development, and (2) provide environmental information to the largest group of environmental managers in Malawi, the smallholder farmer. A study was initiated to determine the feasibility and mechanism by which

farmers could collect environmental data on their own, data that would be relevant to their seasonal farming activities. Surveys were completed in four MEMP catchments which provide information on farmers' perceptions of the cause of environmental change.

Indicators used by farmers include crop pests, wild plant availability, subsistence products such as thatching grass, building poles and fuelwood, crop varieties and rotations, dominant weed species, and termite species. Two indicators used widely by farmers are (1) diminishing soil fertility and rainfall as mirrored by falling crop yields, and (2) declining water levels in streams and wells. There is clear evidence of gender-differentiated indicators of natural resource change; women observed environmental change differently from men, both in individual communities and across catchments. Women were particularly ill-informed about the causes and subsequent environmental effects of the depletion of natural resources, a shortcoming closely allied with female illiteracy and low (or no) levels of formal education.

Agricultural intensification, though not quantified, is occurring because of increasing population densities, and is characterized by (1) shorter rotations and/or fallow periods, and (2) increased intercropping. The study did not consider whether intensification might also include increased rates of adoption of soil- and water-conservation practices. Harvest shortfalls are increasing, as summarized in the socioeconomic survey (Annex 3), with farmers looking to the remaining woodlands and dambo areas for salable timber, charcoal, vegetables, and reeds.

One significant finding of the participatory survey is that in many areas, people seeking information depend less on community-level authorities and sociocultural organizations than do their counterparts in other southern African nations. Such apparent autonomy may be a relict of the previous political system. Regardless of its origin, however, it must be considered in each of the many proposals for community-based development in Malawi.

It is generally assumed that changes in policy result in concomitant changes in environmental management and quality. That this has not been evidenced in Malawi requires donors and the GoM to recast their strategies. One avenue that might be pursued in coming to grips with the social construction of authority is the undertaking of research to gain a broad understanding of the economic and political history of Malawi as these affect resource use.

Due to the highly variable socially-differentiated indicators that the survey produced, it is not clear what is the most appropriate approach to take in developing a participatory environmental monitoring system to complement the computer-based system proposed for GoM agencies. Monitoring change in natural resources provides an opportunity for community education that could result in people's deeper understanding of environmental processes. The information so gained could be used to influence productivity and resource planning, and may assist extension planners as they strive to understand the logic behind farmers' resource allocation decisions. We therefore propose a follow-up to the original survey so as to solicit ideas from individual farmers. We also suggest that informal surveys in the catchments be administered, with information obtained used to refine the indicators list as a function of both the catchment and the specific farming system.

One of the difficulties that has been clarified by the participatory surveys is the level of misunderstanding that underlies problems in communication between local inhabitants and (for example) the forestry service in its attempts to establish participatory forest conservation. With

little cognizance of the social dynamics of environmental change or a local lexicon to describe such change, policymakers often fail in their attempts to enroll local people in mitigative or preventative projects. At the very least, findings presented to local land managers (i.e., the farmers) must be reported in ways that listeners can understand and act on. This mandates the utilization of local terminology, while at the same time maintaining a user-friendly perspective that takes into account local values.

E. Small Grants Research Projects

This component existed in Phase I, but languished. The Small Grants project will be resuscitated in Phase II, in which the person filling the Environmental Scientist position will make sure that the fund is actively used by MoREA and the University of Malawi.

V. Findings: Lessons Learned, Implementation Issues

A. Assumptions

Environmental management is often based on uncertainty and incomplete information concerning environmental issues, and therefore requires an adaptive approach. The following subsection discusses the assumptions inherent in forecasting changes in land use patterns following policy liberalization.

1. Land Use Response to Policy Changes

With a number of policy driven development programs anticipated under the Natural Resources Management and Environment Support Program (NATURE) and the Environmental Support Program (ESP), it is appropriate to discuss a suitable framework for analysis of not only the specific issue of liberating smallholder access to cash markets, but other policy reform issues with environmental implications as well.

There is little question that there is considerable anthropogenic environmental change in Malawi. What is often difficult to understand is why this is occurring and what can be done about it. There are several simple models that might be applied in analyses of these various linkages. We depict three of these simple models (a – c) first, then introduce a fourth (d) that we propose using in the next phase of the MEMP.

a. *The Vicious Circle or Downward Spiral model*

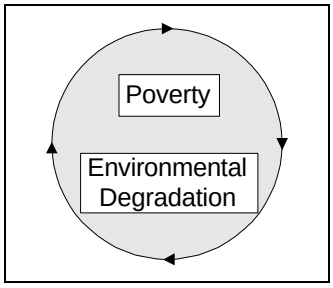

Figure 10. The Vicious Circle model linking poverty and environmental degradation.

Poor households in Malawi often find it difficult to meet their basic human needs. As a result of the limited options available to them, they are often forced to overuse natural resources, thereby degrading the resource base. The resulting degradation further limits the ability of people to break free of their over-dependency on natural resources, and will result in the perpetuation of poverty. The model illustrated by Figure 10 has been termed the 'vicious circle,' due in part to what is viewed as a *direct* link between poverty and environmental degradation. Increasing poverty drives further degradation, which leads to continued poverty.

Concern has been voiced, therefore, that a development program attempting to address poverty issues but reliant on the increased use of the natural resource base might actually accelerate the 'downward spiral' of environmental degradation and possibly exacerbate poverty over the long term. This concern was the initial impetus for the monitoring program now known as the MEMP.

The original program design of the MEMP focused on the status of the natural resource base in the circular model. With the inclusion of the socioeconomic baseline studies carried out by HIID, MEMP has been able to provide information on the relative change in wealth of smallholder farmers who adopt burley cultivation.

b. *The Environmental Entitlements model*

The 'vicious circle' or 'downward spiral' model, has been criticized because it assumes that farmers do nothing, or sit idly by, in the face of accelerating environmental change. The model reflects neither farmers' survival strategies nor their ability to adaptively manage natural resources in the face of change. The 'environmental entitlements' model considers three additional factors, all of which are interlinked: (1) the status of the natural resource base, (2) farmers' ability to manage these resources, and (3) how the first two listed items change over time.

The MEMP is providing tools for monitoring the status and change of the environmental resources in Malawi. With the inclusion of the pilot programs proposed during the past year, such as the Farmer-Based Monitoring component, information on the ability of resource-poor farmers to manage their resource endowment could also be provided. Refinements to this model can be made via the additional use of transects and participatory surveys to ascertain indigenous knowledge and practices within Malawi.

c. The Web of Causation model

The 'environmental entitlements' framework departs from the simple cause-and-effect relationship of the 'vicious circle' model, but it may itself be an oversimplification of the complex issues surrounding environmental degradation. Numerous complex diagrams exist, including the *Nexus of Environmental Degradation* in the *National Environmental Action Plan* (Government of Malawi, 1995), which in their attempts to show all the interactions creating degradation often make it difficult to perceive the underlying causes. A simpler diagram is presented in Figure 11, one that incorporates the economic, social, and political factors known as the *structuring processes.* These processes may have significant, but often overlooked, impacts on why farmers are/are not able to successfully adapt to environmental change.

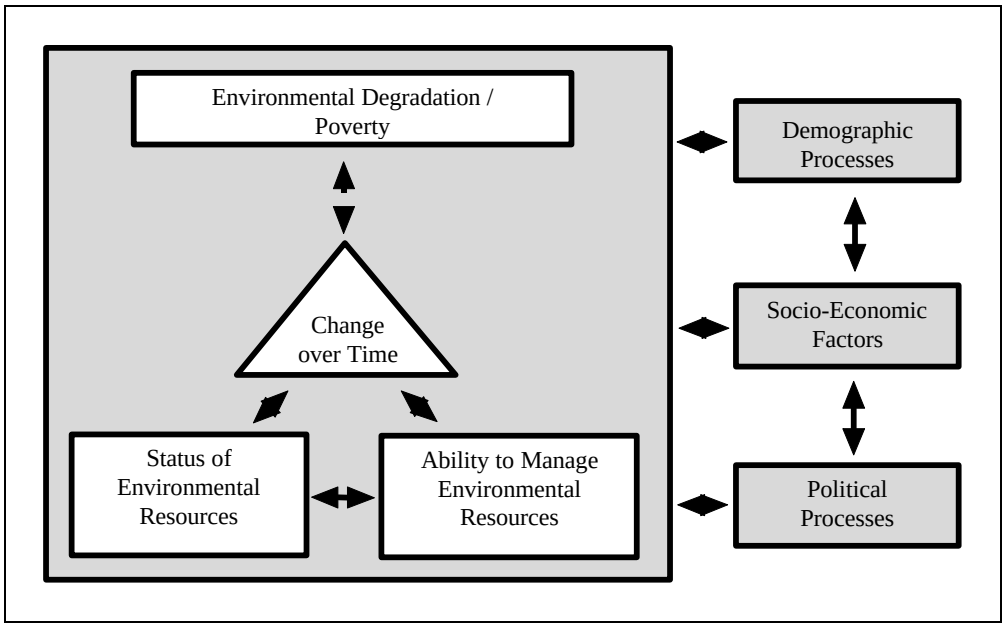

Figure 11. The Web of Causation model linking poverty and environmental degradation.

As discussed above, the number of smallholder farmers adopting burley cultivation during 1993-1995 was less than anticipated, and resulted in a significant program modification in August of 1994. Analysis of some of the structural processes in the 'Web of Causation' model may reveal the reasons for the cautious approach taken by many smallholder farmers in reacting to this policy issue, and may shed light on how they may react to proposed programs under the ESP.

d. The Environmental Cascade model

The Environmental Cascade model continues to enhance the level of complexity inasmuch as (a) the factors contributing to the Vicious Circle model are identified, and (b) the opacity of the Web of Causation model's socio-economic factors (hitherto simply a 'black box') is made transparent. Central to the construction of this model is the earlier work of Prof. C.F. Hutchinson and his model of household options (formerly known as "coping strategies") when faced with food insecurity. The fundamental thesis of the Environmental Cascade model is that each household option has a concomitant environmental impact. The level of difficulty in returning to the *status quo ante* is represented by the slope of the curves in Figure 12. As this tangent increases, households become more and more stressed, while environmental security cascades into realms increasingly difficult to reverse. Once households descend past the horizontal line bisecting the food security quadrant, they become enmeshed in a cycle of poverty from which it is difficult to extract themselves without externally-provided assistance.

The Environmental Cascade model can be used to predict where environmental degradation is likely to occur. In addition to monitoring environmental indicators themselves, the monitoring and identification of their precursors – household indicators of stress – will allow more-timely intervention and mitigation strategies to be devised. On a nationwide basis, existing datasets – such as those collected by FEWS – can thus be used to target locales requiring intensive monitoring activities. Such an approach dovetails with one of the MEMP's policies, which is to make maximal use of prior datasets.

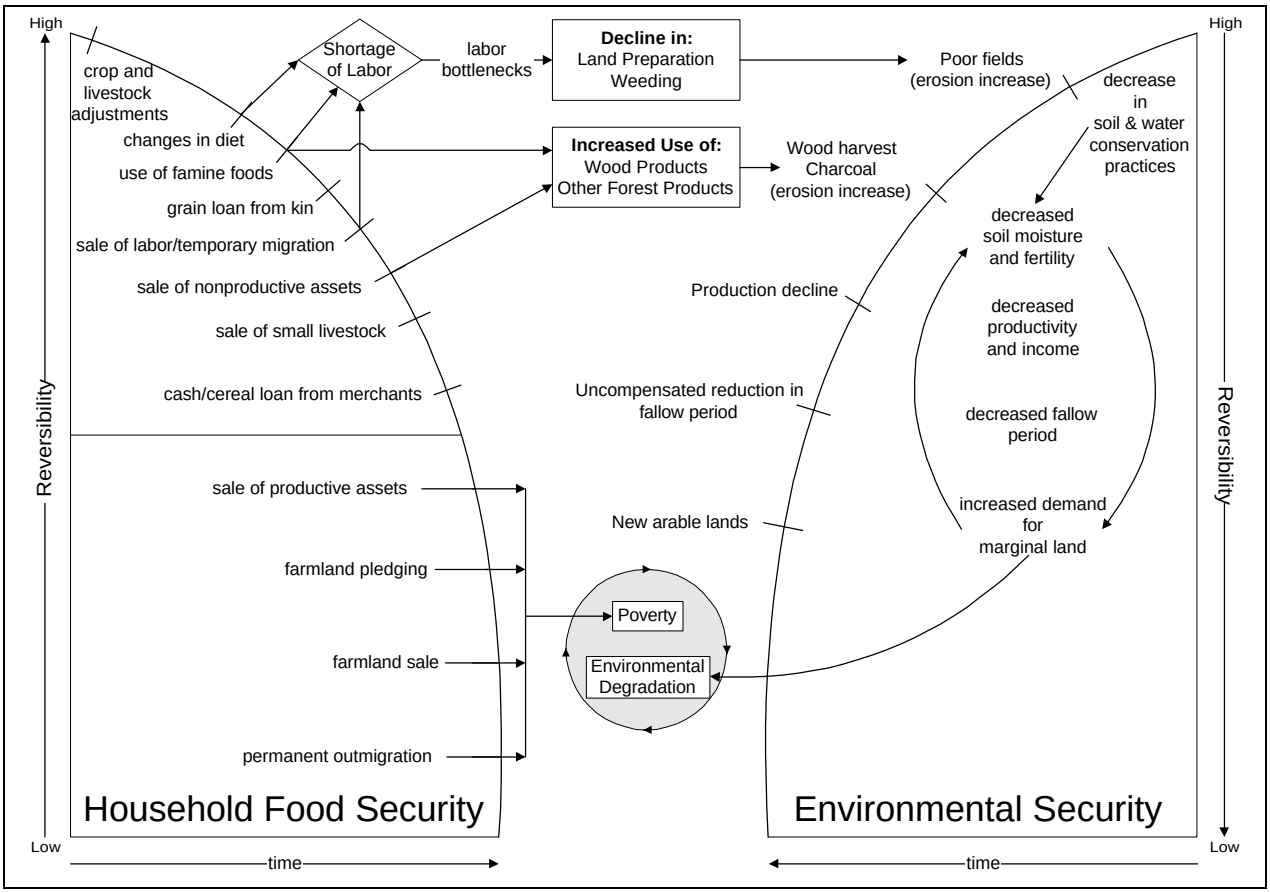

Figure 12. The Environmental Cascade model linking poverty and environmental degradation.

B. Approach

1. Forms of Environmental Management

Environmental management involves three different actions taken either separately or in concert.

- *Preventive actions* seek to avoid future damage to environmental systems. Example: many areas in northern Malawi as yet not impacted by expanding agriculture or demographic pressure.
- *Mitigative actions* reduce or soften the impact of activities that would otherwise become damaging to environmental systems. Example: increasing pressures on natural resources around protected areas in Malawi's Forest Reserves and National Parks.
- *Remedial actions* where prior damage is repaired, and the health of systems restored. Examples: many areas in southern Malawi; those regions impacted by refugees during the 1980s and early 1990s; and current concerns over increased sedimentation of the mid-Shire River drainage system.

2. Specific Monitoring Issues

The four small 1000 ha microcatchments are not representative of any one specific agroecological zone, but offer instead the potential to model different environmental management options. The Ntcheu site has been degraded by Mozambican refugees, and offers the potential to monitor environmental rehabilitation efforts. The Mangochi site faces multiple land and resource allocation issues; these present options for developing strategies to contend with migration resulting from increasing demographic pressure on the land base. The Chulu site shares a border with a protected area, and can be used to evaluate the impacts of increasing use of natural resources in protected areas. The Nkhata Bay site still has approximately two-thirds of the total area under woodland cover. Different approaches to participatory landuse planning for sustainable development could be monitored in this catchment.

Future monitoring sites would be based in areas where soil and water management and conservation interventions are on-going or planned. This would have the dual advantage of measuring the effectiveness of mitigation interventions while demonstrating to local resource users the advantages of adopting soil and water conservation practices.

3. The Need for an Adaptive Approach

Due to the modifications and adaptations made in the technical procedures to accommodate the limited number of smallholders moving into burley tobacco production, the first year's data collection exercises must be considered to largely be a learning experience. Some inferences concerning general trends may be made from the preliminary findings, but with limited confidence because of data quality issues.

The level of effort to develop baseline maps in the current catchments is unlikely to be replicated in all eight agroecological zones or ten farming system zones as has been requested by LR&CB. Regardless of this, interest from other researchers in Malawi in replicating the baseline data in their research areas has been expressed.

Integrating geographic data technologies with farmer-based monitoring still makes sense, and is one of the innovations of the MEMP. In order to link monitoring with mitigation, the agents of change must be incorporated into the planning process. The logical step is to evaluate the responses of the communities to the proposals made in the *Environmental Indicators and Change* report (Annex 1). There is some concern that the concept may be ahead of its time in Malawi. If this is the case, a more passive monitoring and reporting system will be more appropriate.

4. The Value of a Decentralized Approach

The use of remotely-sensed data in several line ministries (Section IV.C) has provided these agencies with the opportunity to monitor environmental change at regional, as well as national, levels. Landuse participatory planning and analysis targeted at specific local conditions has now become possible.

5. The Imperative of a Participatory Approach

There are scores, if not hundreds, of examples of failed development projects scattered all over the developing world. In many cases, the projects collapse once the technical experts or foreign

advisers leave because local people do not perceive how the proposed development can benefit them directly. A participatory appraisal, coupled with participatory project design and implementation, invests local people in their own futures and assures them that their concerns are being considered and included. While not a panacea for guaranteed project success, projects will almost surely failed in the absence of a participatory approach.

C. Problems with Personnel Management

1. Continuity

As in any long-term program, staffing is always in a state of flux. However, this problem is particularly acute in the case of our Malawian colleagues, where the problem is exacerbated by the shortage of trained personnel (refer to Subsection 3 below).

2. Experience in the Environmental Sciences

One of the difficulties in project implementation became noticeable only after some time had elapsed: It became clear that Malawians have not had the training in, exposure to, or practical experience in the environmental sciences necessary to develop the comprehensive strategies required to address the environmental problems facing the country. Rather than obtaining a general level of understanding regarding cause-effect links and problem-solution sets, single solutions are often sought to what may be multi-causal problems.

3. Retention of Technical Personnel

How to contend with the endogenous civil service hierarchy in developing countries is a problem common to many development projects. The difficulty is twofold: either personnel who need no further technical training (and who will not, in any case, work in a technical capacity, such as experienced supervisors) are assigned for training, or personnel trained by a project are immediately promoted to supervisory positions where they are unable to use their newly-acquired skills. In either event, it is difficult to retain qualified technicians at staff-level to do the real work the project requires. The civil service needs a horizontal promotions career path so that trained technical personnel can pursue and sharpen their skills rather than being relegated to administrative functions if they accept promotion under the existing system.

4. Range of Individual Capabilities

The range of individual capabilities was particularly obvious in the GIS training, where some people who were wholly computer-literate and had received prior training in international centers such as ITC, The Netherlands, were placed in the same classroom as those who had never before turned on a computer. In hindsight, this seems a singular waste of opportunities. It would have been far better to have taken those people who already possessed technical skills and to have trained them in problem-solving techniques (refer to Subsection 2 above).

5. Technical and Managerial Capacities

Effectiveness in environmental management and planning is more a matter of performance than of organizational placement in the structure of government. If the Environmental Affairs Division (EAD) wishes to become an effective voice for the environment, it must concentrate on

developing technical and managerial competence – two areas of striking weakness at the current time. The lack of established positions within MoREA has been previously noted to be a factor hampering EAD's ability to accomplish its mandate in the past. Similarly, the lack of technical specialists has also hindered implementation and raises questions regarding EAD's ability to coordinate activities in line agencies that have staff with greater technical proficiencies. Steps have been taken recently to address the problem of understaffing

As of mid-1996, there were 17 EAD staff members. It is essential that recruitment and retention of staff be based on (1) the technical qualifications of applicants in accordance with clearly defined job descriptions, and (2) a coherent strategy relating staffing to organizational priorities rather than to sources of project funding. Improved management of staff and other resources is also essential if EAD is to be accepted as an equal, and authoritative, partner by line agencies and other public and private entities in Malawi.

6. Competition for Scarce Technical Resources

As donor interest in the environment increases, those civil servants who constitute the backbone of line agencies tend to be drawn into a comparatively few activities, often outside the priorities of their own agency. In effect, donors are (a) competing with each other over a limited pool of technical staff, and (b) pulling competent staff away from their functions within their agencies. The net result is that while donor-funded activities might be strengthened, the overall ability of line agencies to function effectively is diminished.

7. Agenda Setting

To contend with the points made in Subsection 6 above, agencies must decide where their priorities lie, and must make these explicit to donors. Such a strategy will assure the precedence of GoM internal priorities over donor priorities.

D. Linkages

1. Decisionmaking

The linkage between the MEMP and the decisionmaking process was always implicit. It was assumed that the information emerging from the monitoring program would be used (1) to inform policy, and (2) to inform mitigation strategies. Because MoREA is not, in fact, a policy-implementing agency, the necessary linkages failed to materialize. The failure to link to the decisionmaking process calls for the future development of institutional mechanisms that are able to address both policy and mitigation needs. Such linkages must be applicable and useful both to decisionmakers and to line agency, field-level representatives.

2. Strategy

Underlying the presumption that the information emerging from the monitoring program would be used in the decisionmaking process was the fundamental – and ultimately simplistic – assumption that if information exists, it will be used. New strategies must be developed, ones that clearly relate data collection to the utility and relevance of the information acquired.

3. Political Commitment

The MEMP is based in MoREA, which is charged with the coordination of environmental programs by implementing agencies in other ministries and must therefore rely heavily on their technical expertise. The agencies themselves are involved in collecting and analyzing new data for the MEMP instead of relying on existing or historical datasets as their primary sources of information. For MEMP to succeed, a high level of coordination among participating agencies is mandatory. The issue of commitment by senior managers in the line agencies should be viewed as key to the successful implementation of Phase II of the program.

Concern over the issue of commitment has led to a proposal to emphasize linking monitoring to current or proposed mitigation programs within line agencies. A closer link between monitoring and mitigation is likely to bring greater line agency commitment.

4. Authority

Another difficulty encountered concerns the authority of the EAD in relation to securing cooperation from line agencies. This issue of authority is tied most directly to the placement of environmental affairs within Government, and is one that emerges routinely in other countries. Until the decision to elevate EAD to department level, EAD was actually at a lower level in the public sector hierarchy than the agencies whose activities relating to the environment it was to coordinate. Even as a department, EAD lacks the hierarchical basis for requiring cooperation from line agencies that are in most cases larger, better funded, and have long histories of working with established clienteles in clearly defined sectoral areas.

Nevertheless, cooperation is best when it is offered rather than compelled, and there is at this point no reason to assume that a change in location in Government is needed for EAD to be successful. Indeed, there is little compelling evidence from other countries that placement under a nonsectoral structure, such as the Office of the President or Vice President, or establishment as a parastatal outside of traditional public sector structures and procedures, necessarily results in an improved ability to execute policies and improve environmental planning and management at all levels within the country. Technical competence of the responsible agency, its ability to provide valued services to public and private sector entities alike, adequate financing, and high level political support are all factors that affect performance more directly than the simple matter of placement.

E. Monitoring Policy Reform

1. The Environmental Management Approach

The original MEMP design strategy, i.e., coupling intensive data collection with extensive sampling, has now become difficult to rationalize. Intensive monitoring in the five microcatchments is unsustainable, for too many opposing factors tend to intrude. Nor is it now practical to consider extensive sampling over the entire country. Instead, one important factor to emerge from monitoring in the five watersheds is that the expertise now exists to monitor as necessary anywhere in the country.

Rather than on the one hand continuing intensive monitoring in the five watersheds indefinitely or on the other hand resorting to extensive sampling strategies, the MEMP should (1) focus on

predicting where environmental problems are likely to be encountered, then (2) mobilize the capacity for pre-emptive, intensive studies. Given the existing limitations in budget, mandate, and human resources, such an approach is appropriate.

2. Mitigation

a. Linking monitoring with research

As it is not yet clear how decisionmakers will respond to the MEMP, it is recommended that in the short term a greater effort be made to link the current environmental monitoring technologies with similar research at the Bunda College of Agriculture, ICRAF, and the Malawi Agroforestry Project. These programs have existing data gathered from similar agroecological zones, from catchment transects, and from village resource-mapping efforts. Further evaluations of the participatory approach (the farmer-based system) can be achieved by working with the already-existing farmer groups available through other programs.

b. Demonstration plots for extension

Greater attention must be paid to coupling the GIS thematic maps, field pits, and control plots with both formal and informal extension messages and programs.

c. Technology transfer

Within each of the agencies involved in the MEMP, a number of products were identified as suitable for development in operational settings. Examples include topographical and infrastructural data, coordinated climatological data, land cover and land use data, etc. It is envisaged, therefore, that specifically-targeted assistance using GIS and related technologies, coupled with services that can be provided by short-term technical experts, will facilitate the development of these products. The products themselves will form the foundation for a National Mapping Program that will serve as the precursor to the planned EIS.

d. Farmer participation

Of the three avenues identified as possible solutions to overcome the impediment of peasant illiteracy – currently a major constraint for participatory research and monitoring activities – one, restricting involvement to those farmers possessing literacy, is ultimately inconsistent with the goals of the MEMP. Such a restriction would preclude the participation of most women, few of whom have had the luxury to attend school. Women frequently view environmental problems quite differently than do men, and may have different ideas as to what the solutions might be and how these may best be implemented. If environmental mitigation proposals are to be accepted by the populace at the grassroots, active participation and acceptance by **all** societal strata must be a sought-after goal.

A second avenue, the development of a procedure that allows information to be recorded pictorially, is a viable short- to medium-term solution, one that will assuredly expand farmer participation in the MEMP. The third avenue is future-oriented; it seeks to involve literate schoolchildren, who could then assist in their parents' participation. Not only does this avenue have the advantage of including environmental issues as a school activity, but it also invests the

next generation of land caretakers with a deeper appreciation of the links among farming, conservation, and their own future.

F. Recommendations

1. Technology Transfer

There are a number of recommendations for specific alterations to the implementation of the technology transfer component of the MEMP. These recommendations have arisen from the observations of the Clark and University of Arizona teams, input from USAID, and from the GoM following the Decision Makers' Workshop.

a. Continued sensitization

Awareness and interest in geographic information technologies has been increasing, albeit at a rate sufficiently slow as to retard the diffusion and adoption process. As a result, it has been difficult to maintain (1) a sense of commitment and continuity among the trainees, and (2) continued support from their sponsoring agencies. Although GoM officers are well trained to carry out their respective tasks, a broader level of awareness among them is needed so as to assure (1) a full commitment to participants in the technology transfer component, and (2) a more effective use of the technology within their respective agencies, both for monitoring and for basic environmental research. This could be accomplished by extending GIS training to senior-level researchers and scientists from each agency, preferably focusing on staff who are able to articulate and initiate research agendas. This would complement the currently trained technicians from MEMP I who are now able to carry out fundamental data development and analysis. Given the time constraints of the senior-level officers, the attempt should be to make them GIS literate as quickly as possible, perhaps through a two-week intensive sensitization.

One of the conclusions of the Decision Makers' Workshop concerned the need to begin sensitization and develop support at much higher political levels within the GoM. It is important that, at a minimum, the level of the Principle Secretary be made aware of GIS technology and its opportunities within the GoM. This may best be accomplished by holding a session similar in format to the Decision Makers' Workshop for such senior-level civil servants.

The first phase of the MEMP has been successful in working with government officers in the ADDs. These government officers are close to the local resource problems, and as such are better able to formulate research agendas that can immediately affect environmental monitoring and mitigation. The landuse mapping analysis and associated activities being conducted by one of the trainees, who resides in the Mzuzu ADD, will do much to increase awareness at this level. Decentralizing the technology transfer implementation process away from the departmental offices and toward the field at the ADD level is therefore a reasonable strategy.

b. Overcoming scientific and research deficiencies

One of the most significant barriers to the adoption of GIS during Phase I has been the lower-than-anticipated level of scientific and research expertise of the trainees, and their lack of capacity within their agencies to initiate, conceptualize, articulate, and conduct independent scientific research related to environmental management. Although the trainees have been adept at

acquiring the fundamentals of GIS, a much broader range of skills is needed to efficiently employ these new technologies. Emphasis must be placed in Phase II on activities aimed at enhancing technical capacities within each of the participating agencies.

A long-term mechanism for addressing these deficiencies will be to institute a GIS education and training process in Malawi. At the university level, two committees, the Post-Graduate Research and the Academic Planning Committees, must be involved in any long-term curriculum planning, including the identification of suitable sites for housing a 'GIS Lab' and training center. During the months of August and September, University faculty are free to attend refresher courses, offering an appropriate window for training faculty in the potential uses of GIS technology. Faculty who may be suited to become GIS trainers can simultaneously be identified. However, it is clear that there is currently a lack of any local expertise to develop curricula and training programs in GIS. During Phase II of the MEMP, therefore, a long-term expatriate technical advisor/faculty member will be placed in the University of Malawi system. This person will be charged with developing the GIS curricula, research, and training programs that will ultimately create and institutionalize local-level GIS capabilities.

c. Infrastructural adjustment

A significant barrier to the continued use of GIS technology derives from the bureaucratic and financial infrastructures currently in place in Malawi's civil service. The reality is that Malawian civil servants are vastly overworked and undercompensated. This has resulted in low morale, and a high level of absenteeism (although sanctioned) to attend the many donor-sponsored workshops and training sessions. Although in general these activities offer positive contributions for government officers, their frequency has had the tendency of disrupting ongoing work assignments. The lure, of course, is the additional compensation paid to attendees. In most cases, attending a week's workshop will earn a civil servant more than a month's salary. Even more, a trip overseas can easily be equivalent to a year's salary. This has had a significant impact on the quality and quantity of routine work, as well as being detrimental to the performance of the new tasks that trainees are being asked to undertake.

Currently there is no personnel structure in place that can accommodate the technical, educational, and salary requirements of GIS analysts. This deficiency, as confirmed by GoM officers, will significantly reduce the chances for success. Government officers cannot adequately carry out these new activities without an infrastructure in place or proper compensation for employing the newly-acquired technical knowledge and expertise. To overcome this hurdle may require the creation of a professional level within the civil service, one that offers an attractive compensation and benefits package. This recommendation may be overly bold, but it is by no means out of place. The acquisition of new technologies should merit a rethinking of existing structures where necessary.

A GIS Users' Group was established early in Phase I of the project, and included representatives from each of the participating agencies and other interested departments (and even staff attached to other donor-sponsored projects). Initial interest waned as it was quickly recognized that without formal acknowledgment by the GoM in terms of financial support and bureaucratic recognition, the Group could not have enough influence. The formalization of this Group is

currently on-hold, but should be encouraged for any future activities. In particular, the Group could play a vital role in the development of a suitable civil service professional grade.

2. Clearly Defined Strategies for Linking Monitoring to Mitigation

As initially conceived, the MEMP was intended to be a national monitoring system. As a result of the World Bank-sponsored National Environmental Action Plan (NEAP), considerable interest has been expressed in the extension of this activity to the development of a national Environmental Information System (EIS). The decentralized character of the MEMP is inherently compatible with an EIS, as any such enterprise will necessarily be a multisectoral effort.

However, the actual (as opposed to theoretical) situation regarding the MEMP has been much more difficult to clearly define and operationalize. The MEMP was designed to inform policy, but it had no built-in link to decisionmakers. Conventional wisdom posited that monitoring should benefit the farmers, and this led to the participatory monitoring component. However, the information that trickled up to higher echelons was rarely, if ever, put to use. This shortcoming will be redressed in MEMP II, which has a hardwired link to policymakers through the Environmental Policy Advisor position.

Even so, there is no method for the MEMP to effect *action*, although certainly a great deal more emphasis must be placed on ways in which recommendations arising from program activities can be reported in ways that enhance and assist the decisionmaking process. Thus, while the MEMP's primary roles are to inform policy and establish saliency, it must also (a) provide useful information to resource managers down to the level of smallholder farmers, and (b) evaluate pathways that can lead to mitigation.

Consider how the MEMP may respond to deforestation activities. Accompanying the loss of tree cover itself are two other attendant impacts that are environmentally damaging. The first is streambank cultivation, which leads to siltation of watercourses. The second is hillslope cultivation as it affects soil erosion rates. MEMP's task, as noted above, includes evaluating pathways that can lead to mitigation of the environmental damage caused by these three simultaneous and linked problems. The suite of responses might include fiscal penalties, complete exclosure, and/or agroforestry or woodlot projects, etc.. The role of MEMP II, i.e., informing policy and establishing saliency, pertains to the relative combination of these tactics that might be employed in specific geographical areas under particular socioeconomic conditions. Simultaneously, the MEMP will succeed if, and only if, it is able to generate information useful to and usable by smallholder farmers – the largest group of environmental decision makers in Malawi.

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VI. Annexes

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MALAWI ENVIRONMENTAL MONITORING PROGRAM

Environmental Indicators and Change

Results of a Qualitative Survey of Smallholders in Four Catchments

Susan Moodie

The Office of Arid Lands Studies
The University of Arizona

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Executive Summary

The Malawian Ministry of Research and Environmental Affairs (MoREA) is evaluating options for establishing an environmental monitoring capacity that (a) strengthens technical and line agencies, and (b) provides the foundation upon which an Environmental Information System (EIS) can be established. This document describes the survey of farmers undertaken so as to better understand farmers' perceptions of (a) environmental change and its causes, and (b) measures of this change. A third goal of the survey was to note the mitigative actions taken against environmental degradation so as to evaluate whether farmers can contribute to a national environmental monitoring scheme.

The survey was conducted during 1994/95 in four catchments (Njolomole, Kamundi, Chulu, and Chilindamadji) where MoREA had been collecting rainfall, sedimentation, and runoff data since August 1993. The survey team stayed eight days in each catchment, meeting with elders, "focus groups" comprised of both genders, and individual farmers. The results of the surveys can be summarized as follows.

Farmers observe changes in a wide range of natural resources but do not discern change systematically. The two indicators that are widely used by farmers are declining soil fertility and rainfall; both serve to indicate changes in yields. Rainfall also indicates the level of water in streams and wells, as well as the number of pests and weeds. Farmers noted changes in natural resources with verbal descriptors or alterations in their behavior.

Indigenous knowledge concerning the weed species that indicate changes in rainfall and soil fertility varies considerably among the catchments. There is also great variability in farmers' perceptions as to why these changes have occurred. Men with more education appeared to be better informed. Women were ill-informed about cause and subsequent environmental effect; there does not seem to be a good flow of agronomic information between husbands and wives, among women, or between communities.

Farmers obtain information about farming from parents, school, and extension. They acknowledge that the information is not always correct, that their skills are limited, and that lack of food and poor health impede their ability to work at full capacity.

Agricultural intensification is occurring with increasing population. It is characterized by a change in farming systems, namely fewer rotations, increased intercropping, and shorter fallow periods. In Njolomole with the highest population, most farmers cultivate continuously unless they are ill or the land is rocky. Harvest shortfalls are increasing, and farmers look to remaining forest and *dambo* areas for salable timber, charcoal, fuel, and reeds. They are also increasingly turning to off-farm employment, and seek opportunities for trade or business. Environmental decline can be expected in areas where farmers lack food self-sufficiency but possess few additional skills.

Farmers do not seem highly motivated to address environmental decline except where it affects production. There is only a very limited understanding of (a) cause and environmental effect, and (b) the concepts of choice and responsibility. Much of the impetus for mitigative action comes from outside the farming community. For the most part, farmers' behavior is conservative, restricted to what they are familiar with. Farmers cited many reasons for their conservatism: little access to information, an extension service that is not responsive to farmer-identified needs, administrative styles that discourage individualism and creativity, and a feeling that "government will look after us." Finally, the inability to meet immediate personal needs adds to the absence of incentives to focus on

longer-term planning horizons. There are however, farmers in every catchment who want information to assist them in protecting their livelihood. This desire was best encapsulated by the farmer from Njolomole who said, "*Just give us the skills and information and we'll make the decisions.*" Identifying the reasons for farmers' inaction provides the opportunity to begin a process whereby farmers become agents of change rather than recipients of aid.

Farmers are likely to voluntarily monitor the environment only if they perceive this as a possible way to improve productivity and profitability. Poor understanding of the causes of changes in natural resources, low levels of literacy, and the immediacy of personal needs pre-empts most farmers' participation. However, only a determination of community needs and priorities through a directed Participatory Rural Appraisal could accurately assess farmers' willingness to become involved in monitoring activities. Whether or not farmers choose to monitor does not in any way diminish the seriousness of continued tree loss, declining soil fertility, and soil erosion.

In addition, meeting MoREA's objectives requires that any monitoring system contribute quantitative data and trends in a way that can be extrapolated to the national level for use by policymakers and planners. Such a system requires consistent indicators, measurements, and methodology across catchments, a willing labor force, a conduit for information flows between collectors and government, facilities to process information, and the bureaucratic will and resources to return analyses in a timely manner and in a format useful to farmers. Government resources are very limited, and an environmental monitoring program would require a resetting of priorities within agencies for training, developing methodologies, and interpreting analyses. A modest pilot project in one or two catchments would enable the various agencies to determine techniques for (a) data collection, analysis, and interpretation, and (b) information dissemination and transfer.

Programs with concise objectives are favored by both donors and government for the ready feedback on their effectiveness. However, programs imposed on farmers from above are unlikely to have lasting impact due to the combined influences of social, economic, and ecological variables. To achieve the broader goal of environmental mitigation, a process approach driven by community-identified priorities is more likely to succeed in the long term. To that end, communities must be assisted in (a) identifying and prioritizing issues, and (b) setting goals and designing action plans. Such a process offers the advantages of being able to tackle a wider range of issues and make better use of agency resources; it will also speed up the dynamics of changing attitudes and allow a faster application of new information or systems. This proactive approach recognizes the social and environmental costs that accompany crises, and the exponential complexity in redressing the situation at this juncture.

The complexity of combined social, economic, ecologic, and agronomic factors precludes a systematic external process to affect change. The process for change must originate with individuals and communities at the grassroots, but the motivation for change is stymied by the need to deal with more immediate needs. However, we deny farmers the tools to decide their own future if we do not offer them the opportunity to participate in a wider process that will ultimately (a) improve their productivity and profitability, and (b) allow them to learn about cause and effect relationships in their own environment.

1. Background

The Ministry of Research and Environmental Affairs (MoREA), with funding from the U.S. Agency for International Development (USAID), is investigating options to monitor changes in Malawi's natural resources under the Malawi Environmental Monitoring Program (MEMP). The objectives of the MEMP were to:

a) determine possible environmental impacts of smallholder burley production; and

b) build a broader technical capacity within MoREA and line agencies upon which a viable environmental information system (EIS) can be based.

MoREA is a relatively new ministry investigating ways to coordinate environmental information from catchment, district, regional, and national levels for use by planners. This survey investigated the feasibility of farmers voluntarily collecting natural resource information for analysis by MoREA.

Farmers are the largest group of natural resource managers in the country, and their combined actions have a huge impact. The social and economic well-being of the largely rural population revolves around agriculture, so it makes sense that government seeks to monitor those natural resource variables useful to decision-making at the farm-level. Voluntary collection of information by farmers is only likely if it improves production and profitability in the short- to medium-term. Thus farmers were asked about what natural resources affect productivity. While indicators of environmental change need not link directly to sustainability, they may be used as signposts pointing to best options for farmers in given resource situations. Indicators are not to be confused with absolute thresholds, which are more problematic to determine.

Farmer collection of information potentially provides a huge and detailed information base, access to data currently unavailable to government or donors, and the opportunity to provide analyses and interpretations of these data in a way that is useful to farmers. Analyses of monitoring brings into focus farmers' immediate concerns, highlights those practices or sites that need ameliorating, and gives impetus for longer-term planning. Understanding the causes of change provides government with the opportunity to work in partnership with farmers, to seek voluntary change in natural resource use while moving toward land restoration, conservation, and more sustainable land uses. This process also allows farmers, extension agents, planners, and policy makers to identify interventions likely to be effective, and sequence them in a way that makes sense to farmers – a factor crucial to achieving policy goals.

2. Introduction

This survey identifies indicators of natural resource change at the farm and catchment level. In addition, it captures the broader social, economic, and political forces affecting smallholders to evaluate the feasibility of involving farmers in an environmental monitoring scheme. Identifying farmers' perceptions of issues would presumably illustrate underlying assumptions, knowledge, cultural norms, and perceived

opportunities, the sum of which are manifested as behaviors affecting resource use. Specifically, the survey was intended to clarify the following:

- What are farmers' perceptions of environmental change?
- What measures do farmers use to determine changes in natural resources?
- What are farmers' perceptions of the effects of their farming practices on the environment?
- What resource use issues have been identified by farmers and what mitigative measures have they taken to address them?
- What are the requirements for incorporating farmers in a monitoring program?
- How feasible is involving farmers in collecting data and information?
- What are the impediments to monitoring by farmers?

3. Methods

The MEMP has been collecting information on water quality, rainfall, sedimentation data, and cropping history in five catchments since August 1993. Four of these catchments were included in this study: Njolomole, Kamundi, Chilindamadji, and Chulu. Two villages in each of Njolomole and Chilindamadji were sampled, and three villages in each of Kamundi and Chulu. Villages representative of catchment conditions were chosen by Land Conservation and Resources Branch (LR&CB), which also hosted meetings to inform residents of the upcoming survey and its purpose. Every effort was made to choose a sample of farmers that was representative with respect to gender, wealth, age, and land size holding. Procedures were sequenced in accordance with respect for Government and Traditional Authority, proceeding from Program Managers (PM) in their respective Agricultural Development Districts (ADD) to their staff, the village headman, and finally to farmers.

The survey team lived in each catchment for eight days. During this period it interviewed separate groups of men farmers, women farmers and village elders. Groups of between 6-10 participants were requested and the high turnout at Nkuchila, in Kamundi, (150+) and Chimombo in Chulu, (150+) was unexpected. Further clarification from key informants was sought as needed. In addition, in-depth interviews were conducted with 35 men and 34 women, and their fields visited to verify information. Half of the women were heads of households. The number of men and women smallholders attending these interviews is listed by catchment in Figure 1.

The survey team consisted of two enumerators, Gertrude Songo and Yob Mkwinda, who were recruited through the Center for Social Research at Zomba, and the coordinator, Susan Moodie, from the University of Arizona. In addition, two women fluent in Yao were hired in Kamundi to assist the survey. The team used a separate questionnaire for elders, focus groups, and individuals. Interviews with elders were to obtain consensus on long-term change in both the environment and in farming systems, and demographic and services information. Focus group interviews provided gender-specific information pertinent to farming practices, decision making, and responsibilities. Individual interviews focused primarily on farming changes in response to changes in the environment. The questionnaire used for individual farmer interviews is contained in Appendix I.

Since time is measured by familial, community, and political events, the following prompts were used to estimate the time of change: independence (1964), end of work in South African mines known as *theba* (1985/86), and first talk of multi-parties (1990/91). Farmer responses usually led to follow-up questions by the survey team that uncovered greater detail concerning village history and customs. This provided the opportunity to place information on targeted issues in the larger context of village life, thus identifying constraints and opportunities to developing a farmer-based monitoring system.

Catchment	Njolomole		Kamundi		Chilindamadji		Chulu	
	Men	Women	Men	Women	Men	Women	Men	Women
Group participants	50	59	69	150+	65	34	102	150+
Individuals	6	11	7	9	9	4	13	10

Figure 1. Numbers of respondents.

4. Summary of Findings

4.1 Smallholders perceptions of change

Some general patterns of perceptions of change emerge from Table 1 despite variation in dates between catchments. There has been a contraction of the rainy season since independence, a gradual lowering of stream and well levels with very noticeable effects in the early 1990s, and decline in crop yields since settlement, briefly reversed with both the introduction of inorganic fertilizer in the late 1970s and hybrid maize seed in the 1980s. Farmers also noted steady loss of forest since settlement. Accelerated deforestation occurred in Njolomole with settlement by Mozambican refugees in the 1980s, and in Chulu, Chilindamadji, and Kamundi with settling of migrants. Farmers reported slower regrowth of trees in all catchments except Chilindamadji, and that the rate of change in both tree cover and soil fertility is increasing.

Other pressures farmers reported as impacting both farming practices and profitability included land sales in Kamundi and population pressures in all catchments. This has led to reduced fallow periods increasing pressure on existing land. Government policy requires smallholders to protect certain tree species in all catchments except Njolomole, leading to tree removal in neighboring forests. MoREA has requested the MEMP field assistants (FAs) to determine if different species are being protected in different catchments, or if they are the same species with different local names.

Conclusion Farmers were most aware of changes that had an immediate or clearly linked impact on productivity and household food security such as declining soil fertility and decreasing water tables.

Recommendation A farmer-based monitoring project should focus on those indicators most readily observed and salient to farmers. Other more sensitive indicators will require training and education before they can be introduced successfully.

Table 1. Farmers' Perceptions of Environmental Change

	Njolomole	Kamundi	Chilindamadji	Chulu
Tree Cover • **at settlement** • **population pressures** • **tree health** • **restrictions**	• full cover before 1900 • forest reserve divided in 1947, rapid tree loss with Mozambican refugees 1987-1992 • declining; trees grow slower • farmers preserve fruit trees on their own plots	• clearing began early 1900s, Kaupa since 1944 • hillsides bought since the '60s, most in the '80s; munda and dambo land for tobacco bought in the early '90s • declining; slower regrowth and little regeneration • 1976 - dambo cleared of furniture timbers by the govt. • Forestry requires them to protect - m'bawa, mlombwa, naphini, ntanga ntanga, nkongo mwa • no cutting at graveyards	• full cover in early 1900's, clearing in Kambale began about 1940 • gradual loss of forest resulting from new gardens as population increased and migrants settled • no reports from farmers • hill top was cleared to accommodate Kamuzu Banda's visit in the '80s • Forestry requires them to retain ng'ona, muanga, katupa, mlombwa, mkulu, muona • Headman in Kambale prevents clearing steep slopes for cropping	• full cover in Chimombo in the 1930s, Mekembambo 1979 - forced resettlement from Ntchenda, Kaizwanga no data • gradual loss of forest since settlement as population increased. Group village headman forced local headmen to accept migrants. • slower regrowth • no cutting in Kasungu National Park. • Forestry requires them to retain - mlombo, mbawa, mlombwa, papadende, muwanga, kachere • no cutting at graveyards
Duration of rainfall • **independence** • **current**	• Oct - Apr • Dec - end Feb	• Oct - Mar • end Dec - end Feb	• Nov - Jul/Aug • Dec - Apr	• Oct - Apr • Nov, then stop, end Dec - beg Mar
Water yield • **streams** • **wells**	• level began dropping in early '80s • less water from mid 80's on; longer waits for seepage in the dry season	• level began dropping in mid 70's; most change since 1990 • longer waits for seepage at wells and dambos in the dry season	• noticeable change in 1991; some streams now seasonal • level dropped noticeably in 1992	• noticeable change since 1991; some streams now annual • shallow wells in streams dry out earlier
Soil Fertility and Stability • **fertility**	• yields declined steadily since 60s, increased in 70s with introduction of fertilizer, gradually fell, rose again with hybrid seed, now falling with fertilizer price increases	• yields steadily declined since '49, rose with the introduction of fertilizers in 1977 and again in the early 80s with the introduction of hybrid maize	• steady decline since settlement attributed to shortening rotations. Some had never heard of crop rotations.	• steady decline in yields for all except those who can afford fertilizer and hybrid maize. Trend attributed to shortened fallows and declining rainfall.
• **stability**	• most practiced some conservation measures; need boundary ridges and plantings and buffers along streams	• hill side ridges are washed away annually	• many did not know about soil conservation techniques. Farmers say offset mounds work better than ridges on flatter land. Ridges wash away; on steep slopes. There are some terraces and boundary plantings.	• many people ridge but not necessarily to the contour and few have the labor, energy or knowledge to construct contour berms. Sheet erosion looks common and there are some gullies
• Information from focus groups and village elder interviews. Numbers of men and women respondents by catchment: Njolomole (53,44), Kamundi (75,164), Chilindamadji (63,34), and Chulu, (110, 170).				

4.2 Causes of change

Table 2 illustrates that farmers in all catchments attribute lower yields to declining soil fertility. Changes in soil fertility have resulted from reductions in fallow periods and rotations. Farmers attribute these reductions to lack of land or food, or to a shortage of labor to work the land. When questioned further, farmers point to the effect of increases in household size and immigration on farming systems, yet most do not see any alternative to continued increases in population.

Men attribute contraction of the rainy season and increasingly erratic distribution of rains within the season primarily to tree loss. The majority of women say they "*don't know*" the reason for the changes in rainfall. Both men and women in all catchments reiterated Biblical prophecies, collectively summed in the quote *"God is whipping us"* (elder's meeting, Kaniymbo, Njolomole).

Men and women in both Njolomole and Kamundi felt weed numbers changed in response primarily to rainfall and then to soil fertility. The range of reasons for changes in weeds was wider for the other catchments without clear agreement between men and women. Men in both Njolomole and Chilindamadji felt lack of rainfall influenced pest and disease numbers, but women and men in other catchments were less sure.

Despite recognizing their own actions in reducing tree cover, there is a pervasive attitude that "somebody else" is causing loss of trees. Tobacco growers and migrants are the culprits in Kamundi, former refugees in Njolomole, settlers from outside in Chulu and Chilindamadji. Smallholders seem not to perceive the cumulative effects of incremental removal of small amounts of timber by many people over many years.

Conclusions Apart from the links between crop yields and soil fertility, and between fallow and the availability of land or labor, no widespread understanding exists as to cause and subsequent environmental effect.

Recommendation Any monitoring project should seek to use indicators whereby both men and women can clearly understand the relationship between cause and environmental effect.

Table 2. Perceived Causes of Change in Natural Resources

		Njolomole		Kamundi		Chilindamadji		Chulu	
		% M	% W	% M	% W	% M	% W	% M	% W
Variable	Farmers attribute change to:								
1. Tree decline	Firewood collection	75	20	71	71	40	50	25	45
	Refugees	75	40						
	Tobacco gardens & sheds		20	28	71			17	
	Migrants opening new gardens					10	25	33	
	Population increase & new gardens		10	43	28	10		58	36
	Charcoal & brick making	50				10			
	Less rainfall	100	10	28	14	30		25	18
2. Rainfall patterns	God	25	20	14	43	30	25	17	9
	Don't know	50	50	43	28	20		25	54
	Lack of trees	50	20	71	14	40		58	
3. Stream & well levels	Lack of rain	75	90	71	28	40		67	36
	Lack of trees	50	10			30		8	
	Don't know	25	20	14	43			17	9
4. Weed species & no.	Don't know			14		10	50	25	36
	Lack of rain	100	50	43	86	30	25	33	
	Declining soil fertility	25	20	28	43	30		8	9
	No change					10			9
5. Pest & disease numbers & frequency infestation	Don't know	50	80	28	28	10	25	33	27
	Lack of rain	75	20	14	28	80	25	17	
	Lack of native habitat			14	14				
	Increased wind dispersal							17	9
6. Crop yields	Declining soil fertility	75	80	71	86	80	50	75	64
	Lack of rain	25	20	14	43	10		8	27
7. Farm system: Fallow	Still fallow			43	57			25	
	No fallow: Lack land/inputs/labor	75	80	28	14	40	50	50	73
	Still rotate	25	20	28	71	70-	25	70	18
Rotation									
	No rotation: Lack land/inputs	30	50		43				

Total number of men and women respondents by catchment: (4, 10) in Njolomole, (7,7) in Kamundi, (10,4) in Chilindamadji, and (12, 11) in Chulu.

4.3 Indicators used by farmers

Tables 3 through 6 summarize farmers' descriptions of changes in natural resource and production variables, and list the measures that indicate change in the variable.

Tree Cover: Farmers across all catchments noted a change in the amount of tree cover and in the height and amount of thatching grass available. Both women and men use the time to collect firewood or suitable building materials as a guage of availability of resources. However, women in Chulu did not mention firewood collection as an issue even though the countryside looked barren. Perhaps the nearby park was used to supply firewood.

Rainfall: Farmers everywhere were adamant that the rainy season had both contracted and become increasingly erratic. None of the indicators representing this change applied across all catchments. Farmers in Njolomole and Chilindamadji were switching to more drought-tolerant maize and cassava varietals respectively. However, farmers in all catchments reported increases in pests and diseases in years of low rainfall. They also noted that native vegetation is slower to regenerate in the past decade, except in Chilindamadji where there has been no change.

Streams and wells: Streams in all catchments carry less water year round than in the past and women are experiencing longer waits for water at wells and dambos beginning earlier in the dry season. Men use the need to irrigate dimba crops as a guage of stream levels, while women determine changes in stream and well levels by the time of year they begin waiting for water. Exceptions seem to be in Kamundi where men did not mention watering dimba crops, nor did women mention waiting for water in Chilindamadji.

Pests and diseases: Farmers reported an increase in all catchments. Measures used to indicate change include time and money spent on control measures, lack of rainfall, and reduced native habitat and food sources for pests. None of these indicators are widely used by farmers.

Weeds: Farmers in Njolomole and Kamundi, as well as men in Chilindamadji, report a decrease in weed numbers in response to less rainfall, while women in Chilindamadji and Chulu say weed numbers have increased in response to decreasing rains. Men in Chulu say that weed numbers are about the same. These differing perceptions may result from different cultural practices such as time of weeding, seed load from past cropping and weeding histories, and local variations in soil type, light, and weather conditions that favor one species over another. There does seem to be agreement concerning the change in weed density in response to changes in rainfall and soil fertility.

Crop type: Changes in crops were reported in all catchments in response to changing rainfall but mostly in response to the need for cash. Cash crops included beans or cowpeas, sunflower in Chulu, and tobacco in all catchments where farmers had sufficient land and labor. Cowpea is a crop grown only by barren or childless women. The indicator is economic and consistent across all catchments.

Crop Yields: The same response was echoed in all catchments: declining yields since settlement with brief rises after fallow, and after the introduction of fertilizers and improved seed. Agronomic indicators consistent across catchments include changes in response to declining soil fertility and rainfall.

The most important economic strategies to improve household food security in response to poor yields were off-farm agricultural work, and increased trading of food and agricultural commodities. Less important were the sale of forest products, use of wild foods, loans from relatives, and receipt of relief maize.

Recommended rotations: Those farmers practicing rotations noted that rotations are shortening in response to pressures for food and land. Farmers in Kamundi were unaware of recommended rotations, and women in every catchment were less informed then men on the value of rotating crops and on farming practices in general. The indicator for changing rotations appears to be declining yields. Lower yields is leading to more land being placed under maize or cassava cultivation.

Fallow periods: Fallow periods are least in Njolomole and Chulu, followed by Chilindamadji then Kamundi. Indicators of change consistent across catchments are the need for land and food.

Intercropping: Intercropping is increasing in all catchments, and in Njolomole the spacing between plants is diminishing in response to land pressures.

Sensitivity of indicators: Farmers use direct and indirect measures of environmental change and these can be categorized as agronomic, economic, and social indicators. Rainfall and soil fertility are direct measures of weed and pest numbers, changes in the levels of streams and wells, and crop yields. In addition, poor rains and declining yields affect farmers need for farm inputs, access to credit, requirements for cash with concomitant effect on forest, dambo, and lake resources, and off-farm employment opportunities.

Men's and women's awareness of indicators is for the most part reflective of their gender roles (Appendix II). Men are cognizant of the time it takes to find building materials and to water dimba cash crops; women noted both the increase in time to find firewood and longer waits for water at wells and dambos. The situation is different in Kamundi and Chilindamadji, where women were doing most of the cash cropping. This is understandable as approximately half of the women interviewed in both catchments are heads of households. In Chilindamadji, one-third of the men derive cash incomes from fish while most women obtain cash from farm products. Polygamous marriages amongst the Ngoni and Tambuka (both Muslims and Christians) leave women to work and raise children basically on their own. This makes women in Kamundi and Chulu, and to a lesser extent in Chilindamadji and Njolomole, primarily responsible for fieldwork even if they do not make decisions about what is grown or the inputs used.

Conclusions Farmer-identified links between variables and indicators seem strongest when they directly impact food production and profitability. These links are changing rainfall and declining soil fertility on crop yields, available land and soil fertility affecting farming systems, crop type being influenced by economics, and weeds changing density and species in response to changing soil fertility and rainfall.

Less sensitive indicators or slow incremental change in variables require longer documentation to conclusively show change. However, these changes in practices are clear signals to planners of stresses in communities, and may assist farmers to visualize and create a different future. Two clear sequences of environmental stress are changes in tree cover and declining soil fertility. They are described below.

Farmers used verbal descriptors such as “thinning” or “less than before” to describe initial changes in tree cover. Further losses in forest resources resulted in changes in behavior such as traveling further to obtain firewood or building materials. Finally, with extreme shortage of the resource, cultural practices normally avoided by the community are tolerated. These include removal of trees along stream sides, cutting of fruit trees, and digging up tree roots – normally avoided to ensure coppice regrowth and a semi-permanent source of wood close to home.

Declining soil fertility without external inputs has led to lower yields. Farmers have responded by changing their system of farming. Fallow periods and rotations are reduced to extend production of the staple crop. Better-off farmers use fertilizer and improved seed if available. Further declines in yields result in farmers cropping more staples, with subsequent yield reductions from both erosion and loss of the rotation effect.

Indicators are useful for revealing trends and gauging farmers' receptiveness to mitigative actions and policy. That indicators are qualitative and generally reflective of a number of variables makes it difficult to accurately quantify thresholds and so decide on points or times of intervention. However, knowledge of environmental trends may link more overtly in the community’s mind the connections between cause and effect, and between choice and responsibility.

Recommendations The discrepancy regarding changes in weed numbers in response to changing soil fertility needs to be clarified. It is proposed to sample knowledgeable farmers to link the indicator to farming system and microsite conditions.

Without ownership or managerial rights of resources, there is little incentive to extend planning horizons of communities and encourage responsibility for actions. The idea of finite resources would more directly link cause and effect, and thus make indicators more reliable. Farmers in all catchments are meeting shortfalls of fuel, building materials, and household food and income needs from nearby forests regardless of whether such extraction is legal. Given the proximity of forests, their cash potential, the absence of other income earning opportunities, and most villagers' skill levels, these forest resources provide the *only* source of ready cash

That so many of the apparent vagaries of farming are attributed to God raises a case for educating villagers on basic biological, physical, and economic processes to better understand cause and environmental effect. This may involve reorienting existing extension efforts, targeting elementary school curricula, and calling on NGO and donor resources.

Forestry policy must align with conservation goals. Currently farmers are required to forego yield and income by retaining timber trees on their own land, which forestry subsequently sells for profit. A sequence of satellite images of Phirilongwe Forest Reserve near Kamundi show that such restrictions, in conjunction with fuel and timber shortages, leads to encroachment of nearby forests and not conservation of trees as intended.

Table 3. Indicators and Measures of Change in Njolomole

Questionnaire prompts **Changes in: (*Variables*)**	Farmer description of change in natural resource	% M	% W	Measures used to show more or less change (***Indicators***)	% M	% W	Id.
1. The way the land looks	Amount of tree cover	67	67	Time to get firewood /building mat.	50	58	X
	Tree species indicating fertility			Kachere, muaphe, phaka,mango			X
	Rate of decline of tree cover	33	8	Only fruit trees are retained on farm plots	17	8	X
	Decline in grass cover and height	83	50	Digging up tree roots	17	17	X
2. Rainfall	Amount	100	83	Crop type/ yield	33	25	X
	Distribution	100	83	Regeneration of native vegetation	17	8	
3. a. Streams	Level of water throughout year	50	42	Dimbas require more hand watering	17		X
	Annual streams dry earlier	67	25				
	Dambos dry up	-	8				
b. Wells	Longer waits at wells/dambos	-	50	Length of women's workday		8	X
4. Crop yields & husbandry							
a. Pests & diseases	Numbers/ frequency of infestation	83	67	Increases in: aphids, kunfunbwa grasshoppers, termites, stalk borers, gonogompuchi, white ants kapuewi, leaf blight, snails, kaluvluvi	17	8	X
	Biggest increase			Stalk borer, leaf blight, white ants			X
b. Weed species	Increase in number	-	8	Changes in rainfall	50	25	X
	Decrease in number	50	57	Changes in rainfall and soil fertility			X
	Weed spp indicating infertile soil			Kaufiti, chilala, covani, nsiriu, msonthe, tsangwi			X
	Weed species indicating fertility	50	33	Manmnaligo	17	25	X
c. Crop type	Change in crop type	67	33	Need for cash	33	8	
				Changes in fertility/rains/pests	32	16	
				Lack labor	-	8	
d. Crop yields	Declining, brief rises after fertilizer or fallow	100	100	**Agronomic**: rainfall, soil fertility	100	100	X
				Economic: Household food security strategies			
				Off-farm work	33	42	X
				Trade	33	8	X
				Forest/dambo products	17	25	X
				Cash cropping	83	33	X
				Government relief	-	33	
5. Farm Systems							
a. Recommended Rotations	Shorter rotations than recomm.	50	83	Less land and lower soil fertility	50	33	X
	Continuous cultivation	50					X
b. Fallow periods	Continuous cultivation	67	50	Availability of land/need for food			X
	Shorter fallow than parents	17	17		17	25	X
c. Intercropping	Increase/ closer spacing of plants	33	33	More area intercropped	17	17	X
	No change in intercropping	17	17				X

* Total respondents: 6 men and 12 women. Percentages may add to greater than one where respondents gave several answers to a singe inquiry. Id. = Indicator, X = possible indicator

Table 4. Indicators and Measures of Change in Kamundi

Questionnaire prompts **Changes in: (***Variable)*	Farmer description of change in natural resource	% M	% W	Measures used to show more or less change (*Indicator)*	% M	% W	Possible Indicators
1. The way the land looks	Amount of tree cover	100	55	Time to get firewood /building mat.	16	44	X
	Rate of decline of tree cover	16	35	Widespread clearing for tobacco farms	16	44	
	Tree species indicating fertility			papaya, banana, mposa, ntete, ntanga ntanga			
	Decline in grass cover and height	33	22	Time to find good thatch	16	11	X
	Cutting of wild fruit trees		22	Availability of wild fruits		22	X
2. Rainfall	Amount	83	88	Crop type and yield			X
	Distribution	83	88	Regeneration of native vegetation	17		X
3. a. Streams	Level of water throughout year	16	22				
	Perennial streams now annual	16	22				
	Annual streams dry earlier		22				
	Dambos dry up		11	Water dimba crops except maize and sweet potato	17		X
b. Wells	Longer waits at wells/dambos	50	67	When the wait for water begins		22	X
4. Crop yields & husbandry							
a. Pests & diseases	Numbers/freq. infestation due to rain	83	100	Increases in: termites, grasshoppers, army worms, leaf blight, kodikodi, mephembzo, chiguduli, mice, monkeys, baboons	50	33	X
	Biggest increase in:			Stalk borer, army worms, grasshoppers, mice, monkeys	33	22	X
				Lack native vegetation	16	33	
b. Weed species	Decreased in numbers	100	100				
	Weeds indicating infertile soil			Kaufiti, msonthe, mbombomtale	83	100	X
c. Crop type	No change in crops	16					
	Change in crop type	16	44	Need for cash	11	33	X
				Insufficient rain/fertility		22	
				Lack access to inputs	11	22	
d. Crop yields	Declining; brief rises after fertilizer or fallow	83	100	Agronomic: rainfall, soil fertility			
				Economic: Household food security strategies			
				Off-farm work	67	55	X
				Trading	33	22	X
				Sales forest products	16		
				Use wild foods	83	67	X
				Cash cropping	16	44	X
				Government relief		33	
				Relatives	16	22	
5. Farm Systems	Recommended rotations	33	33	Availability of seed		11	
a. Recommended rotations	Shorter rotations than recomm.	67	22	Availability of information/land	50	44	X
	Continuous cultivation		33	Availability land / soil fertility		11	
b. Fallow periods	Continuous cultivation	50	22	Need for food. Fallow due to illness/ lack labor	49	33	X
	Shorter fallow than parents	50	66	2-5 years and declining		22	
c. Intercropping	Increase in intercropping		22	More of planted area intercropped		22	X
	No change in inter-cropping	16					

* Total respondents: 6 men and 9 women. Percentages may add to more than one where respondents gave several answers to a single inquiry. X = possible indicator

Table 5. Indicators and Measures of Change in Chilindamadji

Questionnaire prompts **Changes in:**	Farmer description of change in natural resource	% M	% W	Measures used to show more or less change	% M	% W	Possible indicators
1. The way the land looks	Amount of tree cover	50	25	Time to get firewood /building mat.	20	25	X
	Tree species indicating fertility			None reported			
	Rate of decline of tree cover	25		Gradual rate of clearing			
	Decline in grass cover and height	30	50				
2. Rainfall	Amount	100	100	Crop yield	50		X
	Distribution	100	100	Numbers of pests and diseases	60		X
3. a. Streams	Level of water throughout year	50	25	Watering of dimba crops	20		X
	Perennial streams now annual	10	25				
	Annual streams dry earlier	10					
b. Wells	Longer waits at wells/dambos	40	25	Month when waiting for water begins			X
4. Crop yields & husbandry							
a. Pests & diseases	Numbers/ freq. infestation due to rains	60	75	Increases in: army worms,, grasshoppers, kodikodi, mice, monkeys, baboons, makate, stalk borer	50	25	X
	Biggest increases in:			Kodikodi	50		X
	No change	20	25				
b. Weed species	Increase in numbers	20	50	Drop in crop yields	10		
	Decreased in numbers	70	25				
	Weeds indicating fertile soil			Chigu, mveka in decline	10		
	Weed spp. indicating infertile soil		25	Kaufiti	10		
c. Crop type	Change in crop type	70	50	Need for cash	10	75	X
				Lack labor	10		
				Lack access to inputs	10		
				Government prohibits millet- 1968	30		
d. Crop yields	Declining; brief increase after fertilizer or fallow	50	75	Agronomic: rainfall, soil fertility			
				Economic: Household food security strategies			
				Off-farm work	30	25	X
				Trading in fish	30	25	X
				Sales forest products	30	25	X
				Use wild foods	20	50	X
				Relatives			
5. Farm Systems	Recommended rotations	40			40		X
a. Recommended Rotations	Shorter rotations than recomm.	10	25	Availability of information		50	X
	Continuous cultivation	50	75	Less land and soil fertility	10	25	
b. Fallow periods	Continuous cultivation	20	50	Need for food. Fallow due to illness/lack labor			
	Shorter fallow than parents	60	50	3-5 years and declining	40		
	Same as parents	20					
c. Intercropping	Increase in inter-cropping	40		More of planted area intercropped			
	No change in intercropping	10	50		30	10	

* Total respondents: 10 men and 4 women. Percentages may add to more than one where respondents gave several answers to a single inquiry. X = possible indicator

Table 6. Indicators and Measures of Change in Chulu

Questionnaire prompts **Changes in:**	Farmer description of change in natural resource	% M	% W	Measures used to show more or less change	% M	% W	Possible indicators
1. The way the land looks	Amount of tree cover	100	70	Time to get firewood /building mat.	25		X
	Tree species indicating fertility			Muwanga			X
	Rate of decline of tree cover	55	30	Accelerating rate of clearing	58		
	Decline in grass cover and height	9	10	Number of new gardens	33	20	X
2. Rainfall	Amount	64	100				
	Distribution	64	100	Regeneration of native vegetation	25	20	X
3. a. Streams	Level of water throughout year	45	20	Dimba crops require hand watering	25		X
	Annual streams dry earlier	27	20				
	Dambos dry up	27	40				
b. Wells	Longer waits at wells/dambos	82	50	Month when waiting for water starts	18	30	X
4. Crop yields & husbandry							
a. Pests & diseases	Numbers/ freq of infest. due to rains	73	50	Increases in kodikodi, kapuchi, iwenya,	17		X
	No change	27					
b. Weed species	Increase in number	45	50	Changes in soil fertility	25		X
	Decrease in number	27	10	Changes in rainfall	8		
	Change in weed species	18	50	More kaufiti with declining soil fertility		20	X
	Relationship to fertility./ rain			Kabata, kadzandiyama, nyamalonda,			
	No change	36	10				
c. Crop type	Change in crop type	45	20	Need for cash	45	30	X
				Availability of new market nearby	9		
d. Crop yields	Declining; brief rises after fertilizer	73	90	**Agronomic**: rainfall, soil fertility	73	40	X
				Economic: Household food security strategies			
				Off-farm work	36	30	X
				Trade	27	40	X
				Forest/dambo products		30	X
				Cash cropping	54	20	X
				Relatives/ savings	27	50	X
				Government relief	9	50	X
5. Farm Systems	Recommended rotations	82	40	Availability inputs/ information/ land	42	40	X
a. Recommended	Shorter rotations	18	40				
Rotations	Continuous cultivation		20	Lack land / soil fertility/ inputs	8	40	X
b. Fallow periods	Continuous cultivation	45	90	Need for food. Fallow due to illness/lack labor	25	70	X
	Shorter than parents	45	10	2-5 years and declining	33		
c. Intercropping	Increase	64	100	More area intercropped	18	70	X
	No change	18			18	10	

* Total respondents; 11 men and 10 women. Percentages may add to greater than one where respondents gave more that one answer to a single inquiry. X = possible indicator

4.4. Mitigative measures used by smallholders and their efficacy

Farmer-identified concerns affecting farm productivity, profitability, and quality of life were broadly characterized into the three areas of agronomic, social, and economic concerns. Responses are illustrated in Table 7, with agronomic issues listed for individuals in the upper portion and the collective concerns displayed in the lower portion. Agronomic concerns, particularly the cost and availability of inputs, are a concern for the majority of farmers in all catchments. Collective concerns show that cost and availability of inputs, health issues, the availability of equipped clinics at a reasonable distance, and safe drinking water are all considered very important. These social issues dictate the efficiency of farming and the ability to expend energy and time on both monitoring and conservation work.

4.4.1 Soil fertility

Traditional methods of retaining soil fertility are the use of fallow, rotation, and the burying of plant residues. In Chulu before 1990 when most cattle died, farmers collected manures from corralled goats and cattle and incorporated these into fields. Adaptations to declining fertility include changing crop or variety, burying crop residues, increasing intercropping with legumes, alley cropping with pigeon peas in Chulu and Kamundi, and agroforestry in Njolomole. While the benefits to soil fertility from agroforestry will take some years to accrue, alley cropping with pigeon peas provides nitrogen and cash from sale of the peas within the same season. The small quantities of compost and animal manure available on most farms precludes their use on areas larger than home gardens. Compost is not made in Chulu or Kamundi, and in Chilindamadji most kitchen scraps are consumed by poultry.

Fertilizer is now seen by the majority of farmers as the ‘cure-all’ for low yields. Unfortunately it is expensive and frequently not available when needed. The expected boost in yields may not be forthcoming when rains are unreliable, and makes borrowing money at steep interest rates for fertilizer purchases a high-risk decision. In addition, the use of fertilizer masks the loss of nutrients, rooting volume, and water-holding capacity caused by sheet erosion.

Table 7. Farmer-Identified Issues and Mitigative Action Taken

Responses		Njolomole		Kamundi		Chilindamadji		Chulu	
		%M	%W	%M	%W	%M	%W	%M	%W
Agronomic *(responses by individuals)*									
• soil fertility	burying crop residues	100	100	100	100	100	100	100	100
	addition of inorganic fertilizer	80	11			20		18	
	legume rotations	60		60	67	40	50	36	50
	fallow	20	22	20	33	30	75	9	
	alley cropping				20				10
	agroforestry	20	11		17				
	soil conservation works	60	44	60	33	30	25	36	30
• lack of labor at critical periods	fallow	20	55		17	20	25		
	informal work groups								
• lack of rainfall	change crop or variety	40	11	20		10	25		
	plant trees	60		40	17			18	10
• pest & disease management	guard garden			20	17	30			
	synthesized insecticides	20							
	botanical control		22						
• cost & availability of inputs	continue traditional methods		22			20			10
• few markets & low prices	trade in other commodities	20		20		80			
• insufficient land	encourage children to go to school	20		20		40			
• availability of credit	trade/business to increase income	20							
Data above drawn from individual interviews with men and women; (4, 10) in Njolomole, (5, 6) in Kamundi, (10, 4) in Chilindamadji, and (11, 10) in Chulu									
Services - Health *(responses by groups)*									
• lack safe drinking water	identified need		54	46	18	81	53	27	100
• illness affecting labor efficiency	fallow/ rent or lend land		33		73			27	
• money / distance to medical assistance	stay home/ use traditional medicine/ nothing	11		46	18	81	18	27	73
Services - Education *(responses by ags)*									
• school far or lacking in resources	nothing			27	2	31			59
• adult literacy and training opportunities		22			18	13	53		29
Economics *(responses by groups)*									
• lack of money for basic necessities	seek work/ trade/ sell forest products	51		47	21	13		1	15
Agronomic *(responses by groups)*									
• cost & availability of inputs/ fertilizer		88	78	64	86	63	18	53	59
• lack of rain				35	13			18	74
• pests & diseases					73	31		27	
• availability of credit				12	18			41	74
• lack soil fertility/ poor yields		20	54	16					
• lack land/ overpopulation			54	27	2				
• pests & diseases				72	2				
• availability of credit		38		12		50	41		
Collated from focus and village elder interviews. Total men and women respondents: (53,44) in Njolomole, (75,164) in Kamundi, (64,34) in Chilindamadji, and (110,170) Chulu.									

4.4.2 Soil conservation

Approximately one-third to one-half of farmers practice some soil conservation measures. Female-headed households and married women who farm alone knew fewer conservation techniques. These farmers reported increased surface runoff annually washing out some ridges and contours in Njolomole, Chulu, and Chilindamadji. Those few women who had enough energy and labor to construct contour berms and ridges were using their "*best guess*." In Chulu and Kamundi, farmers said that in the past extension agents had always constructed contour berms for farmers without transferring the 'know-how.' In Njolomole, increasing fragmentation of plots with rising population has resulted in more footpaths along plot boundaries, leading to erosion by foot traffic and water movement. Few farmers had heard about using raised footpaths and not one knew how to construct them.

In addition to limited knowledge of methods, farmers say that the recommended measures are not always effective. In Chilindamadji, farmers found that ridges are often washed out on steep land; and on flatter land, offset mounds of about one meter diameter are more effective than ridges at reducing runoff and produce higher yields of cassava.

In Njolomole, lowland farmers reported difficulty talking to upland neighbors who failed to check water movement on their properties that then adversely affected lowland crops. This points to the need for a common understanding and focus for catchment management.

4.4.3 Declining rainfall

Farmers are responding to contracting and erratic rainfall by staggering plantings and changing crop species or varieties. All farmers reported difficulty in locating the desired seed type. Almost all crops are intercropped in Njolomole, many in Kamundi, all except cassava in Chilindamadji, and all except burley and maize in Chulu. Dambo nurseries are being mulched, and farmers report that they require more regular watering than prior to 1991/92. Availability of wild foods is also declining in response to declining rainfall. Women in Nkuchila attribute the disappearance of 'nkhungudzu,' a native edible legume that used to self-seed near compounds, to declining rains.

4.4.4 Pest control

Control of pests and diseases was not mentioned as a high priority by most farmers but represents an important loss of food. One reason that losses are not higher in an essentially maize monocropping system is the high cost of hybrid maize seed, which ensures that the genetically diverse local varieties are still in use. Farmers in Kamundi and Chilindamadji noted that loss of bush habitat was driving monkeys, baboons, wild pigs, and birds into cropland in search of food. Several farmers reported success in keeping these pests from entering the field by locating banquets of dehusked maize on the perimeter of the field. Only the more knowledgeable farmers seemed aware that insect pest numbers and the frequency of infestation is linked to the destruction of predator habitat, maintenance of rotations, and crop diversity.

4.4.5 Tree planting

Tree planting is being undertaken by more than half the men farmers interviewed in Njolomole, with varying success. Failures are attributed to late arrival of seedlings, unsuitable species, and to lack of knowledge about how to plant seedlings. Given the financial divisions in households, it is possible that

planted trees would be used to boost men's cash income. Without explicit efforts to grow firewood and improve fuel efficiency, further loss of forest cover is inevitable. The availability of nearby forests in other catchments impedes more widespread planting, although several farmers in both Kamundi and Chulu said they *"should"* be planting.

4.4.6 Population pressures

Current pressures and growth rates are seen as inevitable by most farmers. Their beliefs are encapsulated in the comments "*go forth and multiply*," and, "*those in the future will have to take care of the future*." The cumulative effects of these attitudes are being seen in declining fallow periods, limited rotations, and the subsequent impact on soil fertility and yields. As population increases, lack of land will likely result in increasing numbers of landless whose only means of support will be poorly paid agricultural work.

4.5 Practices that contribute to decline on smallholders' land

Soil Management. Farming's most important resource is under pressure. The survey team noted poorly constructed erosion controls, changes in farming systems with declining legume rotations and reduced fallow periods, burning of crop residues, cultivation to the edge of streams and gullies, and the digging up of tree roots. All these practices adversely impact soil structure and fertility. Gully erosion was evident in parts of all catchments, and few farmers knew about the loss of nutrients through sheet erosion. Through extension and education, men appear to know more soil conservation techniques than do women (Appendix II). The use and efficacy of techniques are linked to skill, education, and labor availability. That few farmers practice effective controls on the steep slopes of Chilindamadji or on the flatter but easily eroded soils in Chulu is a cause for concern.

Use of fire. All farmers report burying crop residues yet the survey team observed stacked piles of maize stalks in Chulu that farmers intended to burn. Fire is fairly commonly used to clear new gardens in Chilindamadji and for ash fertilization of millet beds in Chilindamadji and Chulu. Farmers generally seemed unaware of the substantial losses of nutrients and biodegradable material that ensue, initially through volatilization and later in surface runoff with the first rains. Fires are generally attributed to children hunting mice, which may indicate that farmers are aware that burning is detrimental but did not want to indicate their awareness to the survey team.

Value of livestock. Except for poultry most livestock are kept as insurance rather than tradable commodities or sources of protein. Without common land for grazing, livestock feed along paths, roadsides, on fallow land, and on forest preserves. Given the small numbers, the nutrients they add as waste is negligible. Stock compact paths and edges of streams, their waste is a source of pollution, yet they offer needed cash during the *'time of hunger'* in the rainy season before harvest. Cattle were important for tillage and transport in Chulu up till 1990, when most cattle died. Farmers report spending less effort on soil conservation since then.

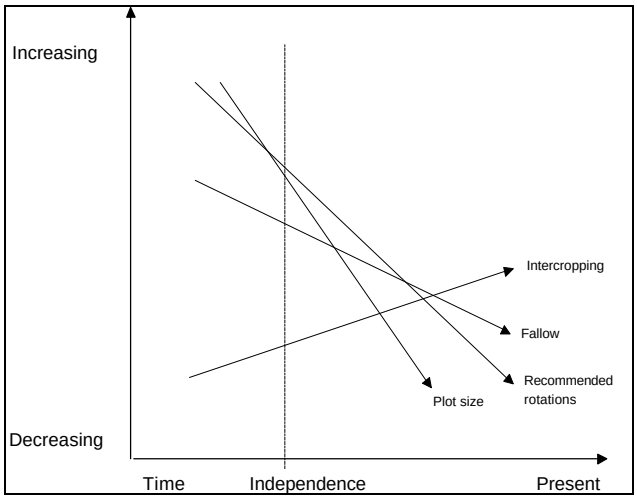

Figure 2. Farming trends.

Population. The effect of family size on farm viability is beginning to be realized by a small number in every catchment. Farmers reported that the family planning facilities to respond to this need are not readily accessible nor of good quality.

Land tenure. Adverse agronomic effects are exacerbated by land tenure arrangements that place pressure on remaining land. These arrangements include sizable leaseholds provided by the government to tobacco growers in Chulu leaving fewer forest resources for smallholders, private arrangements between village headmen and migrants to use customary land, and land sales by headmen to outsiders in Kamundi. Smaller farm size has resulted in shorter fallows.

Conclusions With increasing pressures on existing land, traditional methods of maintaining soil fertility are inadequate. Most farmers see fertilizer as the only solution to maintaining production.

Current information and skill levels to implement soil conservation techniques are insufficient in most catchments. This will continue to affect yields as erosion depletes nutrients. In addition, increasing runoff reduces infiltration and lowers water tables, contributing to declining stream and well yields.

Farmers mitigation efforts are hampered by health issues, lack of labor at critical production times and for conservation work, lack of knowledge, and limited access to information and inputs.

Lack of off-farm low-skilled employment opportunities and increasing population place increasing pressure on remaining forest and dambo areas for salable products, crop land, and wild foods.

Recommendations Provide education at adult and elementary level on the links between cause and environmental effect. Education needs to be interactive, hands-on, visual and probably include combinations of oral, pictorial, and theatrical methods. Information must encapsulate principles rather than just techniques to allow farmers to adapt methodologies to changes in sites and conditions. Holistic approaches to farm management (such as permaculture) embody this exploratory approach

while leaving decisions and knowledge in farmers' domain, and not within administrative orbits that often (a) are influenced by outside policy, and (b) tend toward broad solutions without adjusting for social, economic, and agroecological differences. Education on both the cause and effect of soil erosion and practical demonstrations on conservation techniques would provide farmers with the opportunity to evaluate different conservation methods (a) within their labor and skill requirements, (b) for their appropriateness for various soil types, slopes, and farming systems, and (c) allow them to adapt methods as conditions change. Data from the MEMP plots could be used to demonstrate soil loss by water erosion.

A PRA would accurately determine whether farmers are ready and able to monitor environmental change.

The use of geographic imagery with detail at the plot level would assist in targeting areas for improving farm management according to land capability.

Given the cost and dangers of pesticide use in illiterate societies without protected water, adding to the knowledge of farmers from extension, research, and literature would greatly increase their understanding and options for biological and cultural pest control.

On-going land restoration and conservation practices would be better served by local people knowing how to raise, establish, protect, and manage trees themselves rather than relying on outside sources of seedlings.

4.6 Conditions conducive to mitigative actions

4.6.1 Social organization and group achievements

Existing groups and clubs within villages are the natural focus for any new programs. Chilindamadji has a robust network of both formal business, civic, and recreation groups, as well as informal arrangements to assist with field tasks. One-third of villages in all catchments do not have a club. Achievements by village groups tend to be modest but important given the former political climate and continuous economic strain. Chulu residents constructed a post office now staffed by a government worker. Chimombo residents in that same catchment are helping each other with fertilizer loan repayments and making a commitment to get their children to school. Villagers in Nkulora are building a church/school, and 17 farmers in Kaniymbo are investigating the merits of agroforestry.

While villagers consistently cite lack of labor for field preparation and weeding, collective labor organization is not practiced. However, women neighbors in Chilindamadji help each informally and older women in Kamundi remember working in groups to prepare and weed fields. "*We were friendly then and lived closely*" (Kaupa woman). Apparently the famine of '49-'51 precipitated a change in this area. Women could no longer provide the expected feast in return for labor, and group assistance finally dissipated in the early '80s. Women involved in those groups reported everyone having their fields prepared before the first rains. Such a system makes sense when labor and cash deficits are

common. However, smallholders reported pervasive mistrust, suspicion, and jealousy among people due to unethical actions (selling of land), the legacy of the past political regime, and extreme poverty making many decisions potentially high risk. People did not want others to do well, and cited theft and witchcraft as efforts to maintain the status quo.

Conclusions Formation of goal-oriented clubs (for example, credit acquisition for fertilizer purchases) may not prevent subsequent autonomy and self-reliance. However, these may cloud more immediate individual and community issues such as lack of labor at critical times and the absence of safe drinking water.

Recommendation Identify community issues through a PRA and allow the villagers to set their own agenda and proceed in a way that makes sense to them. A skilled facilitator may be necessary to defuse mistrust and hostility in order to allow community action to proceed.

Moving toward a dynamic that instills group cohesion and harmony will take effort, skill, and a transparent and accountable decision making process. Some were willing to embark on this process but were unsure how to begin. As a younger woman in Chulu pointedly said, "*Show us some examples of how it could be different."*

4.6.2 Record keeping skills

Only the women's chicken club in Chilindamadji reported keeping written records. However, clubs were not asked if they recorded information by other means. Presumably they keep oral records or descriptors of some kind. This is of benefit to farmers but would require conversion and analysis to be of use to administrators.

Conclusions Collection of quantitative data may be difficult where illiteracy is common.

Collection of information and data will only make sense to farmers if the information directly relates to production. If information is collected on useful variables using measurements farmers understand, then farmers will utilize analyses and interpretations in a way that is useful to them.

Recommendations Possible options for monitoring where illiteracy is common are to (a) involve only the literate farmers, which would preclude most women, (b) develop a procedure that allows information to be recorded pictorially, and/or (c) involve literate schoolchildren who could assist their parents. This last option has the benefits of making monitoring both a school activity and a way to get parents and children talking together about farming, conservation, and the future.

Discussion and extrapolation of analyses may provide the stimulus to explore more complex and interrelated issues affecting natural resource use and conservation.

4.6.3 Willingness to try new ventures: risk assessment

Risk assessment can be defined as recognizing the implications of available options and having the requisite knowledge to evaluate alternatives. Much of what the team observed was individuals utilizing a single option presented as a universal solution by government or donors. These solutions included hybrid maize, blanket fertilizer application rates, tillage and soil conservation techniques that do not reflect variable soil conditions, and the introduction of burley and a formula approach to its management.

Additions to these technologies include living sheds for curing burley, agroforestry and alley cropping with pigeon peas to improve soil fertility, and the use of vertiver grass to control soil and water movement. While useful technologies from outside are to be welcomed, it is a cause of concern that farmers are either not looking for or not finding answers themselves. Exceptions were farmers utilizing native root crops (chilazi and bue) to extend food reserves in the dry season, and furrowing mid-season to reduce labor requirements. Almost all women dehydrate vegetables for dry season use.

Conclusion Farmers perceive few alternatives to current farming practices.

Recommendations Orient research to solving farmer-identified issues, and present the results in a form that allows farmers to evaluate the information's usefulness to their situation.

Older farmers said that agricultural films were extremely useful, and favored practical demonstrations.

4.7 Impediments to monitoring

4.7.1 Cause and effect

Farmers' awareness of cause and environmental effect is crucial to their self-identification as decision makers and resource managers. Awareness of basic biological and physical processes is a prerequisite of problem ownership and subsequent resolution. Responses in Table 2 point to farmers either not knowing the underlying causes of changes (for example changes in rainfall patterns or the species and frequency of pests, diseases, and weed species), or being unwilling to acknowledge the effects of their own actions. Despite recognizing their own actions in depleting tree cover, farmers are quick to attribute timber and fuel shortages to the actions of "*others*."

Farmers tend to simplify problems to only those elements that seem important. They focus on what is useful to them, make their best guess, and then test it in practice. Such an approach makes the problem simpler, draws on the farmers' instincts and experience, doesn't require further training or outsider's experience, and allows the problem to be tackled immediately. An example is the use of fertilizer being seen as the 'fix' for declining soil fertility. While this approach is useful in the short-term, other factors whose effects accrue over the longer-term are ignored. These include population pressures and its impact on the farming system, which affect productivity. This is one reason that farmers may miss the links and underlying causes of natural resource problems that accrue over the long-term. Another

reason is the rate of change. Knowledge of processes would assist smallholders to adapt with and anticipate change. Certainly there is considerable local knowledge of the natural environment held by some individuals, but not the deep, widespread knowledge that allows communities to adapt to changing resource conditions in a way that offers yield stability and ecological resistance.

Conclusion While most farmers perceive change in resources, they either do not have clear understanding of the causes, ignore them, or do not extrapolate the changes to their likely consequences.

Recommendation Provide education on cause and environmental effect at the elementary and adult levels. This needs to be coupled to mitigative measures that farmers could undertake. These steps require both suitable curricula and training for those involved.

4.7.2 Agronomic concerns

From Table 7, it is apparent that natural resource issues as they relate to conservation are dwarfed by both agronomic and socioeconomic concerns. The primary concern of communities shown in Table 7 appears to be the cost and availability of inputs, mainly fertilizer

4.7.2.1 Control over decision making

4.7.2.1.1 Inputs

Fertilizer and seed that could have boosted production were either unavailable, available late in the season, located far from the point of production, or were costly. Last year's free fertilizer required farmers in Kamundi to walk a 40 km round trip, half of it with a 50 kg bag of fertilizer on their head. Not surprisingly, most sold the fertilizer in Mangochi and bought other necessities. Low producer prices, access to affordable credit, and availability of markets were also of concern. At Chulu, the government agricultural trading company, Admarc, was buying groundnuts for 2 K per kg, while processed Tambala redskins sold for 27 K per kg in the local supermarket (PTC), a markup of more than 13-fold.

4.7.2.1.2 Information

Access to pertinent and timely information is crucial for decision making by farmers, extension agents, and planners. The information collected must be deemed to be useful by farmers, and it must proceed from the catchment through agricultural administrative units to MoREA for analysis and return. The return trip must be both timely and provide explanation of the results in a way that makes sense to farmers.

Extension agents are logical conduits for information. However, extension agents are clearly overburdened with the number they must reach (1537 families in Njolomole, 1958 in Chilindamadji), the programs they must present or implement, and the data they must collect for their own agency and other projects. Extension agents expressed concern that they cannot get information in a timely manner to assist farmers with their most pressing production needs.

Conclusion Farmers have limited access to information pertinent to their resource situations on which to make decisions.

Recommendation Use the current agricultural structure to feed information from research, literature, extension, and other farmers to farmers. Utilize graduate students at Bunda and elsewhere in conjunction with farmers to develop, oral, pictorial, written, and theatrical material to present new management concepts, perspectives, and ways to document, analyze, and use information.

Having farmers or literate school children conduct some of the monitoring services currently provided by extension agents frees extension to do what they were trained to do – assist farmers with agricultural queries.

4.7.2.2 Low yields

Low yields may result from many agronomic factors that are magnified by poor health and lack of labor at critical times. This may make it difficult for farmers to unravel cause and effect. For example, several farmers in Kambale felt they could considerably improve yields but lacked the money for quality hoes, essential for constructing the large ridges on steep, rocky land infested with bamboo. When asked how the situation would improve if they had new hoes, they responded that they did not have the food, and therefore the energy, to do the work anyway. In Njolomole, several women in Maonga foresaw "*fighting for food"* in the future.

4.7.3 Socioeconomic concerns

Smallholders report that the availability and quality of water, pervasive poor health, and distance to adequately-equipped medical clinics are the major socioeconomic concerns.

4.7.3.1 Land tenure

"*I needed the money so I sold the land*" (village headman, Kamundi). There is confusion about the repercussions of leasehold, the fine line between corruption and receiving gifts, and of responsibility and accountability. While the survey team noted discord resulting from abuses of land tenure, they did not attempt to unravel the complexities of such systems.

Continuing land scarcity and lack of security is crucial to conservation. Management shifts coincide with changes of ownership and control. Shifting cultivation gave way to permanent boundaries in the late '40s in Njolomole, somewhat later in the other catchments. The economic opportunities of population pressures on land have not been ignored by some village headmen. In Kamundi, steep hillsides with fragile soils were sold to newcomers from Dedza, Ntcheu, and Mulanje in the '80s. Liberalization of the burley market saw a fresh round of speculators. They bought the productive flatter fields and dambo areas that were often already occupied or assigned. In Chulu, village headmen are told to accept outsiders by the group village headman. Obviously this causes tension, and it is not uncommon for villagers to employ witchcraft to settle scores. Without security of tenure, conservation works are not a viable investment for smallholders on customary land. This situation contrasts with

owner-operators who seek to maintain productivity of the land for their lifetimes and that of their children. Longer term government leaseholds in Chulu are evidence of this as families actively plan how to both maintain productivity and limit family size.

Conclusions Resolution of land tenure issues is crucial for continued productivity, social stability, and conservation.

Recommendation Utilize a skilled facilitator and mediator to guide interested communities toward a more transparent and accountable decision making process. Refusing to provide land to relatives of villagers and migrants in need (or with money) goes against the grain: "*Charo mbanthu*" (in Tambuka, "the world is people"). A conversation with a village headman in Chilindamadji opened the possibility for a different way of dealing with the implications of migrants and family increase. In essence, the conversation was a move towards democratic and responsible decision making. All members of the village would participate in discussions and decision making. This builds ownership of the situation and some commitment to dealing with its implications. This scenario could easily be extended to cover longer-term resource use. It would engineer social conscience and responsibility and disallow actions, such as those of the village headman in Kamundi, while retaining the traditional reporting structure.

4.7.3.2. Poverty, population, health, and education

"*We never finish the work in the fields because we're always ill, or pregnant, or tired*" (woman at Kaupa, Kamundi). "*When we run out of food we just lie down and sleep to conserve energy*" (man at Maonga, Njolomole). When yields are low, days of one nsima meal a day may stretch into months.

The pattern in the catchments is consistent with consequences of poverty and inadequate access to essentials - sufficient quality food, clean water, adequate sanitation, health care, family planning options and education, that are found elsewhere in the developing world. The major socioeconomic concerns were access to safe and adequate water, illness, and distance to equipped health services, all of roughly equal concern. Distance to inadequately-serviced primary schools followed.

Smallholders experience periodic poor health and acute disability during the rainy season from malaria, diarrhea, respiratory infections, and in Chulu, bilharzia as well. This is the time of greatest energy need to prepare land, sow and weed crops, and work in others' gardens for food or cash to make up harvest shortfalls. Periods of greatest labor requirement are illustrated in Figure 3, the seasonal calendar for Njolomole. The other catchments follow a similar pattern. In 1994/95, these harvest shortfalls averaged 3 months in Njolomole and Chilindamadji, 5 months in Chulu, and 7 months in Kamundi. In every catchment, meat and oil are luxuries, while introduced vegetables are primarily a source of income rather than of vitamins. There was evidence of goiter from iodine deficiency in Njolomole, exacerbated by the reliance on cabbage and other thiocyanate-containing mustards that decrease uptake of iodine. Away from market outlets, a range of wild greens takes the place of cabbage in the diet.

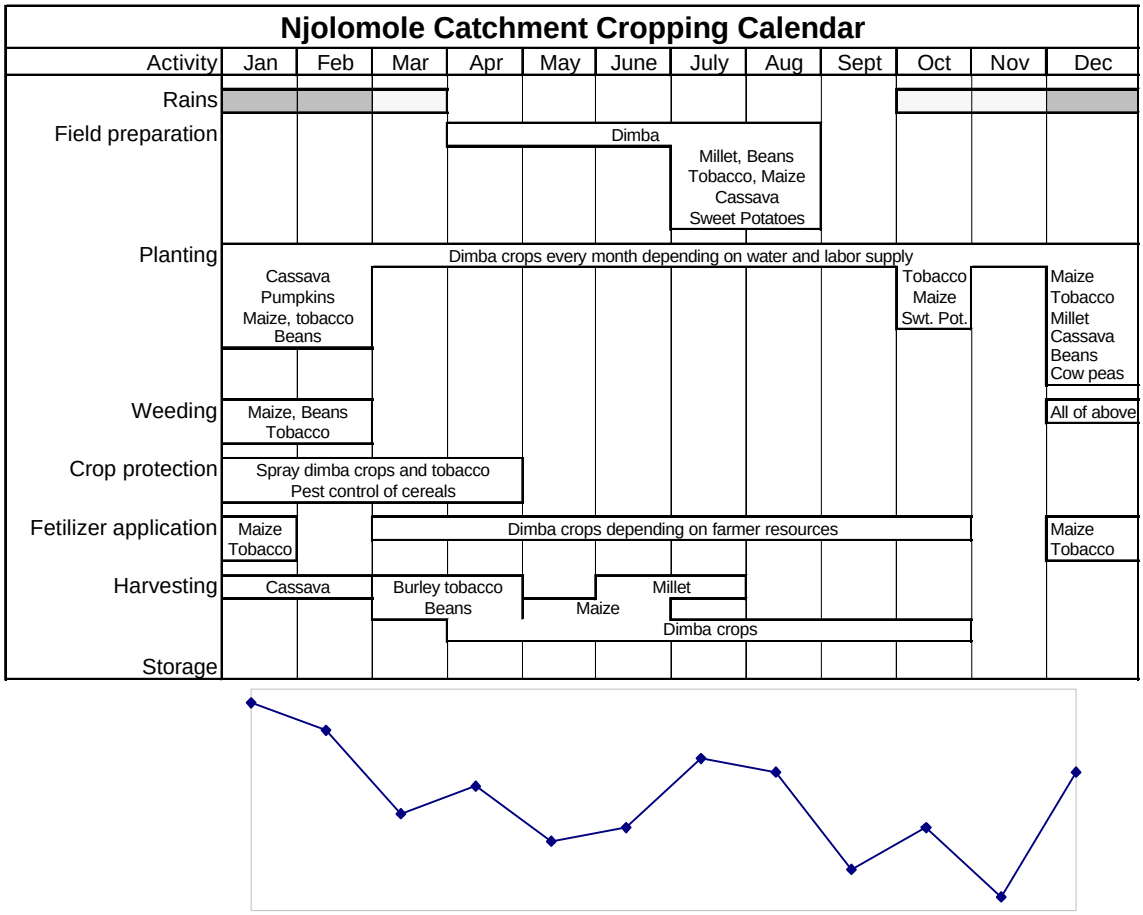

Figure 3. Seasonal calendar for Njolomole. The bottom graph shows relative labor demand by month.

4.7.3.2.1 Choice

"*We sure could do with some condoms around here... and how do you use them*?" (group of women at Nkuchila). Women often have little choice in reproduction, education, or skill development, or in the choice of crop or use of monies. The resultant impact on women's health and opportunities cannot be overstated. In Kamundi and elsewhere, girls are encouraged to marry young because parents cannot afford to feed or clothe them. Early marriage, repeated pregnancies, strenuous field work, child care, and long work days all take their toll. In the dry season, women in Malola spend up to 6 hours a day in collecting a single bucket of water.

Education for women and sensitive family planning services would give women a measure of control over their lives. With high infant mortality, no social security, and technology more expensive than labor, children remain the best option for providing security in old age. There is always the thought that children without land can migrate; to Mozambique from Njolomole and to the nearby forests (protected or not) from the other catchments. The effect of family increase on farm viability is beginning to be realized by a small number in every catchment. Except for a trained midwife in Chilindamadji and an "Under Five Clinic" in Chulu that women stated provided appalling service from a drunken medical

assistant, the attendant family-planning services, education opportunities, and infant care facilities necessary to respond to this need are neither readily accessible nor of good quality.

Conclusion Socioeconomic concerns may overshadow natural resource issues, and certainly impact farmers productivity and profitability.

Recommendation Undertake a PRA to determine communities' priorities.

4.7.3.3 Institutions

"*No one really listens*" - Program Manager - "*..not to women, not to men, not to villagers, not across ministries and not much up and down either....*" Wanting to learn from farmers and making the effort to develop trust is key to strengthening local institutions at the level below district administrations. Ideally, institutional arrangements would seek to include those who bear the costs of monitoring as well as those who benefit from resource management schemes. A specific question worth considering is: When are local institutions most likely to be both effective and sustainable in the management of natural resources? Bureaucracies are often objective driven, while community action relies on the process, the personal interactions between those involved being as important as the outcome. That so few donor projects continue after support is removed attests to the importance of communities deciding priorities, agendas, timing, and methodologies.

Local institutions are more likely to successfully implement environmental management programs if the resource is known and predictable rather than shifting and variable. Further success is achieved when the resource users themselves are an identifiable group or community with their own authority structure. Local institutions are not always able to resolve resource management conflicts, however. If local institutions are absent, all conflicts must be dealt with at higher levels, yielding slower and often less appropriate outcomes. Institutions encourage people to take a longer-term view by creating common expectations and a basis for cooperation that goes beyond individual interests.

While declining rainfall and soil fertility are common to all catchments, some agronomic and socioeconomic issues are village specific. The ability to respond to these issues varies with identification of the issue and local voluntary organization. Similarly, it could be expected that there would be considerable variation regarding responsibility for natural resource management. It is for this reason that any monitoring program must focus on receptive individual farmers and their information requirements in only one sector – agricultural production. If such a pilot proved successful, issues surrounding local institution capacity-building will surface. These issues could be resolved in future phases of a monitoring program.

4.8 A Brief Look at Burley Production

A total of fourteen growers and three club officials from the four catchments were interviewed. The results are to assist the HIID survey later this year to quantify findings. Issues pertaining to natural resource use are illustrated in Table 8.

Failure to repay last year's loan has meant that most tobacco growers used neither fertilizer nor pesticides this growing season. Obviously this lowers yield and quality, and has the added effect of slowing canopy closure that leads to increased surface runoff and sedimentation. In response to limited credit availability, the number of growers has dropped from 30 in 1992 to 7 this year in Chilindamadji. The vice-president of the Nkuchila club in Kamundi said that men can raise money from other activities besides farming to purchase fertilizer but that women could not, either because of household responsibilities or because their husbands associated women involved in business with prostitution. In the same catchment, two growers said the labor investment does not give the necessary profit and food security, and they are better off growing maize. Elsewhere, farmers reported that despite the labor demands, erratic rainfall and cost and availability of inputs, they would continue to grow burley. None of the growers interviewed said they had either reduced or stopped growing other crops as a result of growing burley, which suggests that only the larger landholders grow burley, that fallow land is brought into production, or that burley contributes favorably to household food security and income.

Few farmers report using pesticides. This may lead to lower tobacco quality and price received, but has the benefit of reducing the use of poisons near dambos where villagers in three catchments collect drinking water. The health risks and costs associated with pesticides make investigation of safer, cheaper biological and cultural alternatives an attractive option. One grower reported using a tincture of Elephant Killer *(m'mphanjovu*), a local plant to control pests in tobacco and maize.

The recommended rotation for burley is being followed by only two of the farmers interviewed. Inter-cropping with pumpkins is not recommended but widely practiced to pay laborers and to shade out weeds. The seed is sown one month after tobacco is transplanted to avoid competition for light.
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Table 8. Smallholder Burley Production

Source Indicators		Njolomole	Kamundi	Chilindamadji	Chulu
Agriculture					
• **input use**	• cost & avail causing declining soil fertility	• little fertilizer use - slow canopy closure - greater runoff and erosion expected.	• lack money for inputs	• lack money for fertilizer	• lack of credit limits fertilizer use • few use pesticides
• **rotations**	• lack of land limits rotations	• recommended rotations not followed - lack of land , need for maize	• biannual rotation of tobacco/ maize because of need for food	• enough land to use recommended rotations	• people walk far to their gardens and to available markets. Illness affects labor availability and productivity year- round
• **labor**	• dimba crops require work at same time as tobacco	• labor demand very high at tobacco harvest, moderate demand from dimba, and other crops	• some may stop growing - high labor needs conflict with food production and poor returns	• moderate to low demand for other crops when tobacco harvested	• risk heightened as rainy season becomes less reliable and cost of fertilizer increases.
• **risk**	• high risk when obtaining credit for fertilizer and rains are uncertain	• high risk if no rains	• high risk if rains poor	• farmers are more diversified here	• high risk if rains are poor
Forest					
• **shed materials**	• sheds need renewing about every 2 years	• shed materials from forest; one grower started a living shed	• high demand for timber from large estates - some met with own bluegum plantations	• forests thinning but still plenty of trees	• poles from fallow regrowth and probably the game park. Large estates growing flue cured have high timber needs
• **new gardens for tobacco**	• new gardens pacts soil fertility as little fertilizer is used and recommended rotations are not followed	• existing land converted to tobacco	• land being bought by outsiders for tobacco	• not known	• leaseholders who have more cash, and those capitalized by Limbe Leaf
Water					
• **use**	• bucket watering of tobacco nurseries has little impact	• bucket watering of nursery has little impact	• little impact	• little impact; farmers share watering	• nurseries are usually rain fed
Life Support Indicators					
• **Biodiversity**	• clearing for new gardens further fragments remnant forest threatening their genetic robustness.	• tobacco growers tend to be larger farmers	• clearing of land by speculators in tobacco	• clearing for new gardens by migrants	• clearing of leasehold
• **Special Lands (wetlands)**	• decrease in dambo vegetation with introduction of tobacco nurseries.	• increasing use of dambo ;nurseries moved yearly to reduce disease	• dambo areas well utilized for all crops	• few burley growers	• plenty of dambo land available
Human Impact Indicators					
Health					
• **Water quality**	• unprotected wells may lead to fertilizer and pesticide residues	• most wells capped	• open streams, lot of illness, few use pesticides	• open streams -illness	• open streams - illness.
• **Occupational hazards**	• no safety equipment for spraying pesticides	• no safety equipment	• no safety equipment	• no safety equipment	• no safety equipment
Food Security	• variable, depends on input use, agronomic practices, skills and timing, price received, rainfall	• can be positive or negative for the reasons described at left.	• some will stop - labor demand too high	• credit for fertilizer a problem	• will keep growing

Socioeconomic effects to be ascertained by Harvard Institute of International Development in 1995.

4.9 Summary

This survey was initiated to understand farmers' perceptions, assumptions, and decisions that impact natural resource use. The study determined the feasibility and mechanisms by which farmers could assist MoREA meet its mandate of a national environmental monitoring capacity.

Many farmers perceive changes in a wide range of natural resources variables but do not discern change equally. Thus, measurements revealing more or less change in a variable were not always consistent within or between catchments or between men and women. Two indicators that are widely used by farmers are declining soil fertility and rainfall. Both serve to indicate changes in yields, and declining rainfall is an indicator of water levels in streams and wells.

Indicators of change were either descriptors such as those used to describe changes in forest cover ("thinning," "less"), or intensification of behaviors such as those used to describe the effect of pest increases (more time guarding the garden) and poor yields (needing longer periods of off-farm work and more salable forest products). Farmers obviously quantify yields, but this information was not collected by this survey. There was contradictory information about the causes of changes in weed numbers and species. The differences need to be correlated to cropping history, management practices, and microsite conditions.

Farmers obtain information about farming from parents, school, and extension. They acknowledge that the information is not always correct, that their skills are limited, and that lack of food and poor health impede their ability to work at full capacity. Women seem particularly ill-informed about farming practices and there does not seem to be a flow of agronomic information between husbands and wives, among women, or between villages. More farmers are growing burley tobacco, legumes, and sunflower to meet cash needs. Local forest and dambos or wetland areas are also being harvested for timber, charcoal, fuel, reeds, and wild foods for income. This is to be expected where farmers have few skills and employment opportunities. Without food self-sufficiency and commitment to manage natural resources for the longer-term, continuing environmental decline can be expected.

Much of the impetus for mitigative action comes from the donor community. Farmers report that the introduction of pigeon peas, as well as new varieties of cassava and maize, are useful. However, the majority do not seem motivated at the individual or community level to find solutions to declining tree cover even when the need becomes pressing. The reasons farmers gave are many: little access to information, an extension service that is not responsive to farmer-identified needs, administrative styles that discourage individualism and creativity, and a feeling that "government will look after us." There is limited understanding of cause and environmental effect, as well as of choice and responsibility. Finally, the inability to meet immediate personal needs adds to the absence of incentives to focus on longer-term planning horizons. There are, however, farmers in every catchment wanting information to assist them in protecting their livelihood. This desire was best encapsulated by the farmer from Njolomole who said, "*Just give us the skills and information and we'll make the decisions.*" Identifying the reasons for farmers' inaction provides the opportunity to begin a process whereby farmers become agents of change rather than recipients of aid.

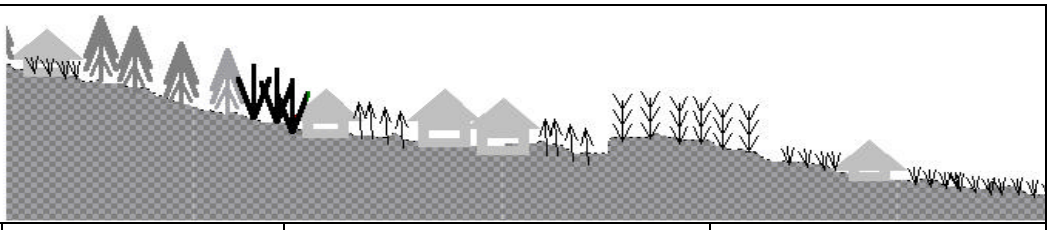
Farmers are only likely to voluntarily monitor if they perceive this as a possible way to improve productivity and profitability. Poor understanding of the causes of changes in natural resources, low levels of literacy to record information, and the immediacy of personal needs probably precludes most farmers from wanting to participate. However, only direct questioning and determination of community needs and priorities through a PRA could accurately assess farmers' willingness to be involved. Government resources are very limited, and an environmental monitoring program would require a resetting of priorities within agencies for training, developing methodologies, and interpreting analyses.

Meeting MoREA's objectives requires that any monitoring system contribute quantitative data and trends in a way that can be extrapolated to the national level for use by policy makers and planners. Such a system requires consistent indicators, measurements, and methodology across catchments, a willing labor force, a conduit for information flows between collectors and government, facilities to process information, and the bureaucratic will and resources to return analyses in a timely manner and in a format useful to farmers.

Monitoring change in natural resource provides the opportunity for education of the community in understanding environmental processes. The information could be used to affect productivity and resource planning. Such information may assist extension planners as they target and sequence useful interventions through their deepened understanding of farmers' knowledge, attitudes, and economic realities. The only way to determine if farmers are interested in this indirect longer-term investment in their livelihoods is to ask them directly. It is suggested that a skilled facilitator be employed to do this. If groups or individuals were interested in monitoring, a pilot is proposed for the upcoming season. This would enable farmers, extension, and MoREA to formulate a system for integration of collecting methodologies, compilation and transfer of information, and analysis and interpretation of results. However, MoREA's analytical facilities are currently over-extended and lack required equipment, and its technical staff require additional training.

Whether or not farmers choose to monitor does not in any way diminish the seriousness of continued tree loss, declining fertility and soil erosion. Materials currently available could be utilized by extension to show trends in resource use. These include farm and village resource maps, quantification of yields, catchment transects such as Figure 4, and GIS images displaying broad-scale changes. Planners also could use monitoring to verify changes in production patterns and farming systems.

Programs with concise objectives are favored by both donors and government for the ready feedback on their effectiveness. However, programs established in response to external stimuli when neither the goals nor sequence have been identified by farmers are unlikely to have lasting impact due to the combined influences of social, economic, and ecologic variables. With the larger goal of mitigation, a process approach driven by community-identified priorities makes sense. To that end, an attempt needs to be made to assist communities to identify and prioritize issues, and to set goals and plans of action. Such a process offers the advantages of being able to (a) tackle a broader range of issues, (b) make better use of agency resources, and (c) speed up the dynamics of changing attitudes and application of new information or systems. This proactive approach recognizes the social and environmental costs that accompany crises, and the exponential complexity in redressing the situation at this juncture.



	Hilltop	Slope	Dambo
Soil	Makande - sandy with organic matter	Katondo - red loam with/ without clay, gravel, sand Nchenga - sandy soil	Makande - alluvial sand
Water	Chimombo and Kaupa households obtain water from wells or streams.	Nkuchila has a protected well, Malola residents get water from perennial stream, N'godi or dambo.	Source of water during the dry season. Seepage is slow.
Vegetation	Native vegetation includes m'bawa, mlombwa, mitwana, mchenga, mtondo, muwanga, mkalati, mdyombo, mtsatanyani. Northern boundary cleared for maize and burley.	Native vegetation on fallow land includes msondoka, mpinji, thombozi, mtondo), chitimbe, napini, mapoza, mango, mtowo, mtangatanga, mthethe, kankhande, mpama. Lipe is a grass used for thatching, mlaza for mats.	M'bawa and mkundi cut down by government in 1976. Other trees include mkuyu and mpembu. Bango is used for mats and nsenjele (elephant grass) for thatching and doors.
Crops - mostly for food	Maize, Irish potatoes, beans, pigeon peas, sorghum (beer), groundnuts.	Maize, groundnuts, cowpeas, pigeon peas, sweet potato, cassava, pumpkins (pay laborers).	Sugarcane, bananas, maize
Crops - mostly for cash	Sesame (a few farmers)	Sunflower, burley, cassava (lake), sorghum (beer).	Vegetables, beans, soya beans (few), rice
Resources Management (Land Husbandry Practices)	Ridges, some stone boundaries and contour berms.	Ridges, some box ridges, stone boundaries, some boundary plantings with either sorghum, bananas or elephant grass, contour berms take too much labor.	Make very large ridges to hold moisture within the ridge, nursery beds for vegetables and tobacco.
Forestry Practices	No common lands; tree removal on smallholder and public land.	Clearing for new gardens on land purchased from village headman. Guavas and mangoes usually retained.	Clearing by government in 1976, and by farmers for gardens, tobacco farms, and firewood.
Food Security		Cook bananas and mangoes. Few wild relish species left - denje, nkuta, bonongwe, nkouta, ntambe, ng'ombe, mpurluse, chisoso, masanjala, chewe and chitimbe fruit/ banana bark for bicarb. of soda. Fruit - mapoza, mpama, mposa, masuku, mphinji, sakalawe, mbulukututu, ndawa, mbembu, nkangandembo.	
Issues		Steep slopes in places, loss of fertility through soil erosion, distance to get water, firewood.	Much energy required for clearing and making ridges, dambo dries out early, gardens require watering.
Opportunities	to be identified by PRA		

Figure 4. Transect of Kamundi catchment.

Appendix I. Farmer Survey Questionnaire

A: HOUSEHOLD INFORMATION

1. Sex..... 2. Age..... 3 . Education..... 4. Main occupation.....
5. Part-time work (when and where) .....
6. Marital status of Respondent. Single..... married..... divorced..... separated.....widowed..... polygamist.... spouse living away..... other (specify)..... Is respondent Head of Hhld? Yes/No
7. Number of children.....

QUESTIONS ABOUT LAND

8. When did you start farming here? .....
9. How did you get your land? .....
10. How many fields do you have? .....
11. How many munda fields? ..... dimba ?..... munda/dimba ..... fields in hills..... home garden ....
12. How big is your farm? .....
13. Do you rent or share fields? If yes, explain how this works .....
14. Do you have enough land to feed your family? .....
15. What do you do when you need land and all existing land is taken? .....
16. Are there any fields you no longer farm? .....
17. Why do you no longer farm them? .....
18. Do you hire people to work on your fields? ..Yes/No...If yes, what jobs do they do? .....
19. How long do you usually employ them? .....

QUESTIONS ABOUT CROPS AND SOILS

20. What crops do you grow on this field? 1= maize, 2= tobacco (burley/flue cured) 3 vegetables, 4= groundnuts, 5= ....., 6= ....., 7= .....
21. Is the crop mostly for sale or food? .....
22. What type of field is it? dimba..... munda..... dimba/munda ..... hillside..... home garden .....
23. What is the local name of this soil type? .....
24. What makes it different from other soils? .....
25. Where is it usually found? .....
26. What crops are usually grown on it? ....
27. What happens to this soil in heavy rains? .....
28. If it runs, why do you think this happens? .....
29. Is this soil type fertile? .....
30. What characteristics does a fertile soil have? .....
31. How do you compare the fertility of the soil now to when you started farming? .....
32. If soil fertility has changed, what do you think are the .....
35. What do you do with plant residues? .....
36. Do you incorporate animal manures into your crop fields? .....
37. Do you practice crop rotation?. YES/NO If yes, what is the rotation? .....

Why do you do this? .....

If no, why not .....
38. Do you fallow this field? If yes, for how long?.(years).....If not, why not? .....
39. What grows on the field during the fallow?.....
40. Are there any crops or varieties you used to grow but have now stopped? .....
41. When did you stop? .....
42. Why did you stop? .....
43. Are there any crops or varieties that you have recently started growing?.....
44. When did you start growing them? .....Why did you introduce them? .....
45. Are your maize yields higher or lower than when you started to farm?.....
46. When did they start to change? .....
47. Why do you think they changed? .....
48. If yields are lower, have you tried to raise them?....If yes, explain what and did it work?.....
49. Where did they get the idea from? .....
50. Have you done anything else to increase yields? .....
51. What are the most important factors to growing a good crop? .....

EROSION
52. Which soils are more likely to erode? (local names)
.....
53. Why do you think these soils erode?
.....
54. Is there any erosion in this field?
.....
55. Is there more or less erosion on your field than when you started cultivating it?
.....
56. Have you ever done anything to try to reduce erosion?. YES/NO If yes, what. and when? (IF NO GO TO 60)
57. If yes, where did you get the idea from? .....
58. Did it work?..... Why/why not? .....
59. Who did the work? .....

QUESTIONS ABOUT SOIL CONSERVATION PRACTICES
Practice Use (Y/N) Effective (Y/N) Why?/Why not?
60. Contour berms .....
61. Contour strips with trees.....
62. Contour strips with grass.....
63. Boundary planting.....
64. Terraces.....
65. Box ridges.....
66. Silt traps in gullies.....
67. Raised foot paths.....
68. Where did you get the information about these practices?.....
69. Have you heard of other measures that reduce soil erosion?.....If yes, what? .....
70. Why haven't you tried them? .....
71. Are there things that you used to do to retain soil but no longer do? .....If yes what? .....

72. If yes to 68, Why are they no longer done? .....

TOBACCO
73. Do you grow tobacco? YES/NO If NO, GO TO 81. If yes, Burley? or Flue-cured .? (circle)
74. If burley, when did you start growing it? .....
75. What inputs do you use? fertilizer (type) ..... amount/ha? ..... Manure.....
pesticides? (type) .....Others .....
76. Where do you get seed? .....credit?..... material to cure tobacco? .....
77. What type of field do you grow tobacco on? .....dimba.....munda..... specify.....
78. Is your tobacco nursery right by the stream? Yes/No .....
79. Does the tobacco nursery displace other crops? .....
80. Are there other crops you no longer grow because you grow tobacco? If yes, what crops and why don't you grow them?.....
81. What rotation do you use with tobacco? .....
82. Are there any problems with growing tobacco? .....
83. Do you plan to continue growing tobacco? .... Yes / No Explain .....

FOOD SECURITY
84. How many months did last years' maize harvest last? .....
85. How do you make up the shortfall? .....
86. What proportion do you buy? ..... borrow (friend/relatives)..... trade ..... other .....
87. What do you do for food when the harvest is bad (such as in 1992)? .....
From the answers above, probe
88. Work?..... If yes, full-time or part-time..... where?.....
89. Sell? ..... If yes, what? (Personal items, livestock, other).....
90. Do you sell firewood, baskets, crafts, charcoal, bricks..... if yes,....where do you get the materials? .....
91. Is the amount of these materials declining?.....If yes, has the rate of decline changed?.....If yes, explain .....
92. If the amount of materials has declined, what has caused the decline? .....
93. What are you doing about it?..... If nothing, why?
.....
94. Do you plan to do anything about it? .....
95. Do you use **wild foods** to help make up the shortfall? If yes, what? .....
96. If yes, where do you get them? .....
97. Do you use wild foods when maize is **NOT** scarce? .....If yes, what?.....
98. Have there been changes in the supply of these foods?..... If yes, when did you first notice the change?
99. If there is a change, what do you think has caused the change? .....
100. Is there anything else that you do when the harvest is very bad? .....

LIVESTOCK
101. What livestock do you keep? .....Number? .....
102. How many do you sell each year? .....
103. Where do you graze them? .....

104. Is there a cattle dip in the village? ...If yes, how often is it used? .....

ENVIRONMENTAL CHANGES

105. Have the rains changed since you started farming? .....Amount?..... When did they start? .....
if there was a change, how.....
106. What do you think has caused this change? .....
107. Is there a stream nearby?...If YES, How has it changed since you started farming? .....
108. If there was a change, what do you think caused this?.....
109. Do you collect water from a well?. YES/NO If yes, has the level changed since you started farming?.....
110. If the well level has changed, What do you think has caused the change? .....
111. Describe how the vegetation has changed in this area since you started farming? .....
112. What are the main causes of this?.....
113. Are some species disappearing faster than others? YES/NO If yes, which ones and why?
114. Do you think it is a problem? YES/NO Explain.....
115. If you think it is a problem what are you doing about it?.....
116. Have the number and type of weeds changed since you started farming? YES/NO If yes, explain
117. If there has been a change why do you think this has happened?.....
118. Are there more crop pests than when you started farming? ..... If yes, state what type .....
119. If yes, why do you think this has occurred?.....
120. If yes, what are you doing to control them? .....
121. Are there more diseases than when you started farming? ..... If yes, what kind? .....
122. If yes, what are you doing about it? .....
123. What are the major problems you face as a farmer? List and explain. .....
.....
124. Which are the most important? .....
.....
.....

IS THERE ANYTHING ELSE YOU WANT TO TELL US?

.....
.....

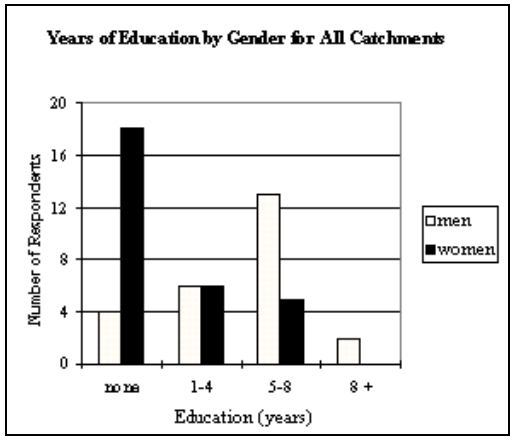
ENUMERATOR OBSERVATIONS

.....

THANK YOU !!

Appendix II. Decision Making and Education Levels

Decision making by gender	Njolomole		Kamundi			Chilindamadji		Chulu		
	Kaniymbo	Maonga	Nkuchila	Malola	Chimombo	Nkhulora	Kambale	Mekembambo	Kaizwanga	Chimombo
Women say:										
choice of crops grown is made by:	women	women	both	men	both	women	women	men	men	men
work decisions are made by:	women	both	men	men	men	both	men	men	both	men
Decisions about work are made by:	both	men	men	men	men	men	men	women	men	men
payment for inputs is made by:	men	men	men	men	men	men	men	women	men	men
Men say:										
choice of crops grown is made by:	men	men	men	men	men	men	men	men	men	men
work decisions are made by:	men	men	men	men	men	men	men	men	men	men
decisions about inputs are made by:	men	men	men	men	men	men	men	men	men	men
payment for inputs is made by:	men	men	men	men	men	men	men	men	men	men
In Chimombo, crops grown on lands that both men and women work are for cash. In other villages and catchments, crops grown on lands that both men and women work are for cash and food.										



MALAWI ENVIRONMENTAL MONITORING PROGRAM

FORESTRY SAMPLE PLOT REPORT

M. LAWRENCE, N. SATO, AND T. CHAULUKA

FORESTRY RESEARCH INSTITUTE OF MALAWI,
PO BOX 270
ZOMBA

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1.0 INTRODUCTION

This reports presents the preliminary analysis of a sample plot survey of the woodlands in the MEMP catchment areas. During the months of September to November 1995, the survey was carried out jointly by members of the Forestry Research Institute of Malawi (FRIM) and Forestry Department Headquarters in three of the four MEMP Catchment areas. These were Kamundi (Mangochi), Chulu (Kasungu) and Chilindamaji (Nkhata Bay). Njolomole (Ntcheu) was not included in the survey due to the lack of afforested areas within that catchment.

The survey aimed to quantify the woody resource in each catchment area. The resource was quantified in terms of the number and composition of the woodland areas as well as the end-use to which each tree in the plots would be put if used there and then. The results will enable the MEMP project to look at changes in the woody resource over time and, in conjunction with socio-economic surveys, to what extent smallholders growing burley tobacco affect this resource.

2.0 METHODS

In each catchment, area plots were randomly located in each of the woodland classes stratified by satellite imagery. The random points were computer-generated from the digitized satellite data. More points were selected than were actually needed as some of the points selected had already been cleared by the time the field team reached them.

Within each woodland class (strata), for each catchment area three Permanent Sample Plots (PSPs) were laid. These plots ranged in size from 0.01ha to 0.04ha depending upon the density of stocking. Due to the short time allowed for the survey it was only possible to measure 3 PSPs per strata. This gives a low precision and more PSPs are necessary for greater accuracy. The accuracy for each woodland class for each catchment is given in the results.

The precision of these PSPs for any particular parameter can be calculated from the following

Install Equation Editor and double-
click here to view equation.

formula:

where n = number of plots
p = the precision
CV = Coefficient of Variation of the chosen parameter
(CV = (s/0) where s = sample standard deviation and 0 = sample mean)

The precision of the results was found using DBH (Diameter at Breast Height, i.e., 1.3m above ground level). It is not possible to calculate the accuracy for the end-uses due to the qualitative nature of those data.

Throughout the results, the precision of the data as sample representatives of each woodland type in each catchment area is quite low. In order to achieve a greater precision, more sample plots are needed. Alternatively larger plots can be used. More numerous, smaller plots are more advantageous in these catchments due to the difficulty of laying out large plots in such densely stocked areas. Also a large number of plots will cover the range of topographic features more evenly.

3.0 RESULTS

3.1 Some results from the forestry products survey

From the socio-economic forest products survey, Table 1 shows those products that were ranked by the villagers as the most important.

Table 1. End-Use Ranked by Importance

Rank	***End-use***
1	*Fuelwood*
2	*Poles*
3	*Rope fibre*
4	*Fruit*

The most preferred species with their associated end-uses are shown in Table 2.

Table 2. Species Representing >1% of the Total Preferred Species: End-Uses for All Catchments

Rank	% of total species chosen	Species	End-use
1	10.00	Julbernadia paniculata	Fuelwood, poles, hanging racks, medicine
2	9.53	Brachystegia boehmii	Fuelwood, rope fibre
3	5.58	Pseudolachnostylis maprouneifolia	Fuelwood, poles
4	5.02	Uapaca kirkiana	Fruit, fuelwood, poles, medicine
5	4.89	Julbernadia globiflora	Fuelwood, rope fibre
6	3.72	Brachystegia spiciformis	Fuelwood, poles, rope fibre
7	3.49	Azanza garckeana	Fuelwood, rope fibre, fruit
8	3.25	Mangifera indica	Fuelwood, fruit
9=	2.79	Lanea discolor	Fuelwood, hanging racks
9=	2.79	Bauhinia thonningii	Fuelwood, poles
11=	2.33	Diplorhynchus condylocarpon	Poles, fuelwood
11=	2.33	Brachystegia spp	Fuelwood, rope fibre, poles
13	2.09	Eucalyptus spp	Poles, fuelwood
14=	1.63	Brysocarpus orientalis	Poles
14=	1.63	Brachystegia floribunda	Fuelwood, rope fibre

3.2 Kamundi catchment (Mangochi)

Table 3. Description of the Woodland Classes

Class	
3	Open woodland
3(9)	Scrub woodland
3(12)	Regeneration
4	Forest
6	Forest

3.2.1 Precision of the results

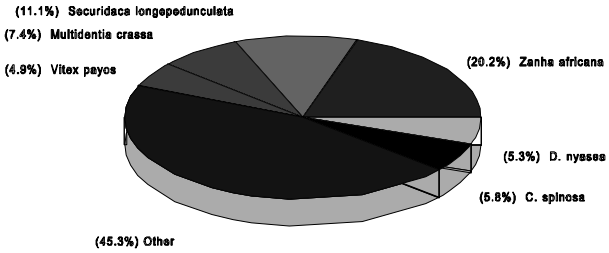
The results presented below for the Kamundi catchment must be viewed with some idea of the precision of the data in mind. Within each of the three Woodland Classes, there was time to lay only three sample plots. The precision of these plots are presented in Table 4.

Table 4. Precision of Plots in Kamundi Catchment by Woodland Class with Regard to DBH

	Precision within Class		
	3	*4*	*6*
DBH	*35%*	*45%*	*51%*

3.2.2 Species composition

The forest areas within Kamundi catchment were split up into five types of forest according to the digitized data from satellite imagery. These were classified as regeneration, open, scrub woodland, low canopy cover forest, and forest with a denser canopy cover (see Section 3.2.3, Table 5).



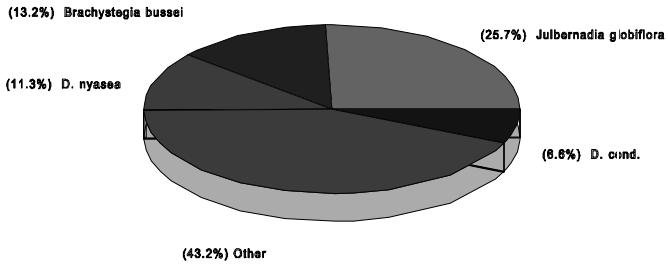
The three groups open, regeneration, and scrub, were originally separated by the satellite imagery. These were all put into one Class after ground truthing the area. This Class is known as Class 3. Class 4 is the low canopy cover woodland and Class 6 is the denser canopy cover woodland.

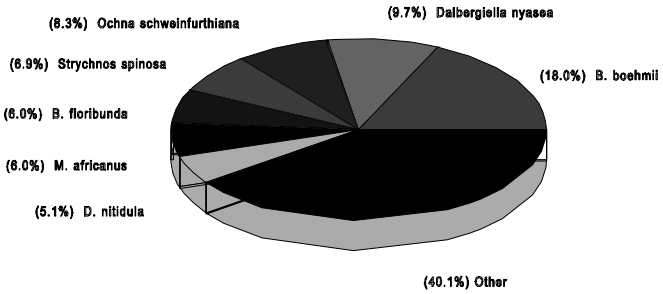
Class 3 woodland consists of areas that have either been badly degraded/deforested or is agricultural land left fallow. The dominant species can be seen in Figure 1.

The species that comprise >5% of the total number of stems per hectare differ in all three Classes. The only exception to this is Dalbergiella nyasea, which occurs in all three Classes at >5% of the total stems per ha. Full details of the species composition of each Class can be found in Appendix 1. Some of the species found in Classes 4 and 6 have been classed as unknown.

Dalbergiella nyasea is used primarily for poles. It only accounts for 0.47% of the preferred species chosen during the forest products survey, however. In fact, out of all the species representing >5% of the species composition of the three woodlands types, only 2 species in Class 4 and 2 in Class 6 are found in Table 2, the list of species that represent >1% of the preferred species for all the catchment areas. These are Julbernadia globiflora (Ranked 1st) and Diplorhynchus condylocarpon (Ranked 11th=) in Class 4, and Brachystegia boehmii (Ranked 2nd) and Brachystegia floribunda (Ranked 14th=) in Class 6.

The other species representing >5% of the species composition of Classes 4 and 6 are illustrated in Figures 2 and 3.





The lack of preferred species raises serious questions about the over-exploitation of these species, and underscores the need to address this issue through proper management of these woodlands. Within Class 3 woodlands the first 'preferred' species from Table 2 is Julbernadia globiflora, ranked seventh, and comprises less than 5% of the woodland.

There is also the need to thin out the areas due to the very high stocking (refer to Table 8). Some management techniques are suggested in Section 4.

3.2.3 End-uses of the woody resource

Table 5. End-Uses within the Class 3 Woodland

	class 3	
<USE>		
firewood	1,900	34.2%
small	1,808	32.6%
pole	850	15.3%
racks	417	7.5%
fruits	175	3.2%
medicine	133	2.4%
rafter	133	2.4%
fibre	67	1.2%
other	67	1.2%
SUM	5,550	100%

Table 7. End-Uses within the Class 6 Woodland

	class 6	
<USE>		
small	1,000	49.0%
firewood	617	30.2%
pole	142	6.9%
racks	100	4.9%
medicine	75	3.7%
fibre	58	2.9%
fruits	33	1.6%
rafter	17	0.8%
SUM	2,042	100%

Table 6. End-Uses within the Class 4 Woodland

	class 4	
<USE>		
small	2,775	46.7%
firewood	1,542	25.9%
pole	700	11.8%
fibre	450	7.6%
racks	267	4.5%
medicine	100	1.7%
fruits	67	1.1%
rafter	33	0.6%
other	8	0.1%
SUM	5,942	100%

In order to determine the end uses of the trees currently in the catchment, a local villager accompanied the forestry personnel. He was asked as to what use each tree within the plot would be put to if it was to be used there and then, even if this meant felling the tree. Much of the resource found in Kamundi was too small to be of any practical use. The "small" end-use category was the dominant category in Classes 4 and 6, comprising 46.7% and 49% of the total number of end uses per hectare for Classes 4 and 6 respectively (Tables 6 and 7).

Class 3 had fuelwood as the dominant end-use (Table 5). This is surprising as this is the 'regeneration' class and as such is expected to have the greatest proportion of seedlings. It is possible that grazing is more common on fallow land, and that therefore the seedlings are grazed.

If the 'small' category is ignored, the overwhelming uses of these woodlands are fuelwood followed by poles.

The third highest end-use differs between woodland categories 3 and 6 (racks), and category 4 (fibre). It is interesting to note that the racks come from both woodlands with a high number of

standards and also from regeneration woodlands. Class 4 has a lower canopy cover than Class 6, and fibre is an important product from this woodland.

3.2.4 Diameter distribution and stocking of the woody resource

Figure 4 illustrates the diameter distribution of the Kamundi catchment woodlands. Class 3 has the lowest proportion of stems in the <1cm class and Class 6 the highest proportion. This is the opposite of the expected results, i.e., where the regeneration woodland would have the greatest proportion of seedlings. A possible reason is that these woodlands have been cleared, or left fallow, within the recent past and the seedlings have all grown at approximately the same rate into the 1-5cm class. There is little variation in the diameters within this class of woodland. The rest of the graph proceeds as expected, with Class 6 becoming dominant in the higher DBH classes. Class 4 is an intermediate woodland with less small stems and more larger stems than Class 3, and vice versa with respect to Class 6. Table 8 shows the stock density of the woodlands.

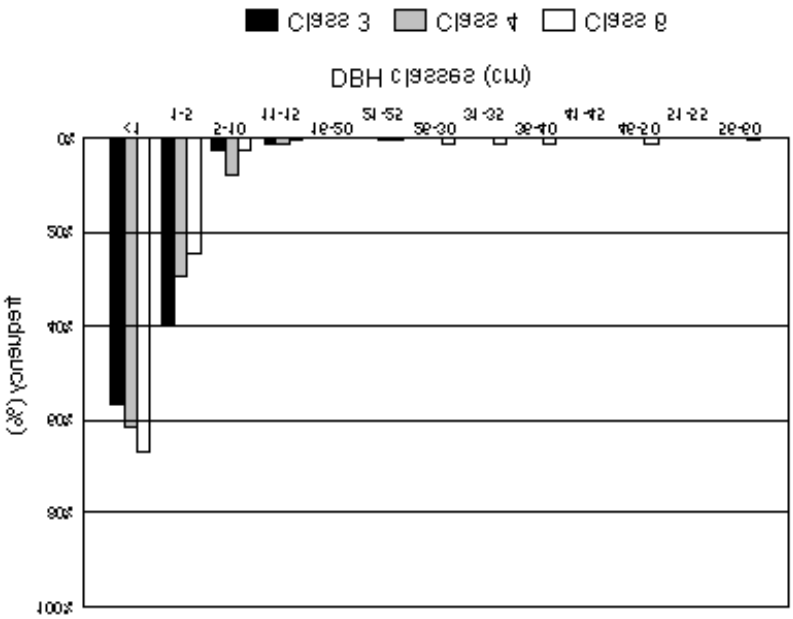


Figure 4. Diameter distribution of Kamundi catchment woodlands.

Table 8. Stems per Hectare of the Three Woodland Classes

Woodland Class	*Stems per hectare*
3	*3,600*
4	*3,671*
6	*1,808*

Classes 3 and 4 are highly stocked and some form of management is necessary for these woodland to reach their potential. Class 6 has a more beneficial level of stocking for a coppice with standards management regime. Classes 3 and 4 need to be thinned out soon in order to stop the stands from going into check and stagnating. The area should be thinned to at least $^{2}/_{3}$ of the current stocking followed by another thinning within the next 5 years down to $^{1}/_{3}$ - $^{1}/_{2}$ of the current stocking. Each area should be thinned for preferred species and products. The type of thinning will depend upon the products - ie. complete coppice or thinning with standards. These management methods will be discussed further in Section 4.

3.3 Chulu catchment (Kasungu)

Table 9. Description of the Woodland Classes

Class	
11	*Scrub/regeneration woodland*
22	*Forest*

3.3.1. Precision of the results

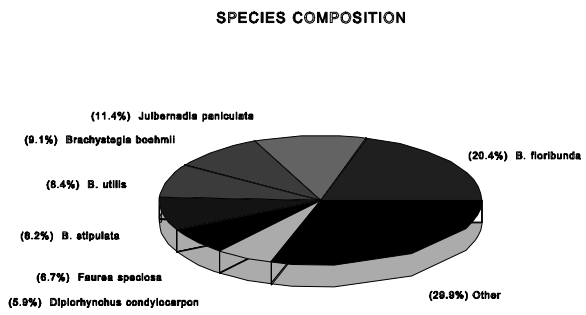
The precision of the plots are presented below :

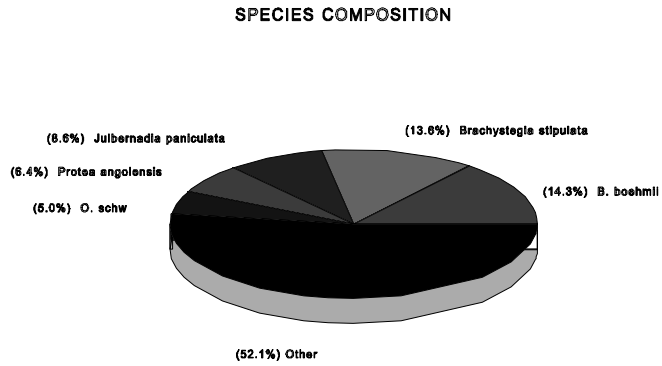
Table 10. Precision of Plots in Chulu Catchment by Woodland Class with Regard to DBH

	Class 11	*Class 22*
DBH	*46.7%*	*63.1%*

3.3.2 Species composition

Figures 5 and 6 show the species composition of Class 11 and 22 woodlands.





Both woodlands have the two most preferred species (J. paniculata and B. boehmii) representing >5% of the woodland composition. Class 11 also has D. condylocarpon (Ranked 11=) and B. floribunda (Ranked 14=). The presence of these preferred species may be due to the very large size of the catchment area and the comparatively lower (human) population density compared with Kamundi. B. floribunda is especially abundant with over 20% of Class 11 comprised of this species. This is a preferred species for fuelwood and rope fibre.

3.3.3 End-uses of the woody resource

As with Kamundi, the fuelwood and poles categories are dominant once the small category is discounted (Tables 11 and 12). Within Class 11, fuelwood and poles are in greater proportions than the small category. Nearly half of Class 22 is designated small. This woodland has far more standards than Class 11, which is dominated by B. floribunda (20.4%) used for fibre and fuelwood (Table 2). In order to acquire the fibre, small stems are generally preferred. Small stems are also used for kindling. Even though the Class 11 woodland is smaller in terms of diameter, it has potentially greater use (see Section 3.3.4), and also has a greater variety of end-uses. Both these observations have important implications for the management of the woodlands.

Table 11. End-Uses within the Class 11 Woodlands

Class 11		
Firewood	*1,433*	*22.9%*
Poles	*1,358*	*21.7%*
Small	*1,133*	*18.1%*
Medicine	*675*	*10.8%*
Fibre	*625*	*10.0%*
Racks	*325*	*5.2%*
Charcoal	*283*	*4.5%*
Gum	*133*	*2.1%*
Fruits	*125*	*2.0%*
Caterpillars	*117*	*1.9%*
Fishing	*17*	*0.3%*
houseware	*17*	*0.3%*

Carvings	*8*	*0.1%*
Fence	*8*	*0.1%*
SUM	*6,258*	*100%*

Table 12. End-Uses within the Class 22 Woodlands

Class 22		
Small	*700*	*48.0%*
Firewood	*317*	*21.7%*
Poles	*233*	*16.0%*
Fibre	*100*	*6.9%*
Medicine	*25*	*1.7%*
Latex	*25*	*1.7%*
Fruits	*17*	*1.1%*
Racks	*17*	*1.1%*
Gum	*17*	*1.1%*
houseware	*8*	*0.6%*
SUM	*1,458*	*100%*

3.3.4 Diameter distribution and stocking of the woody resource

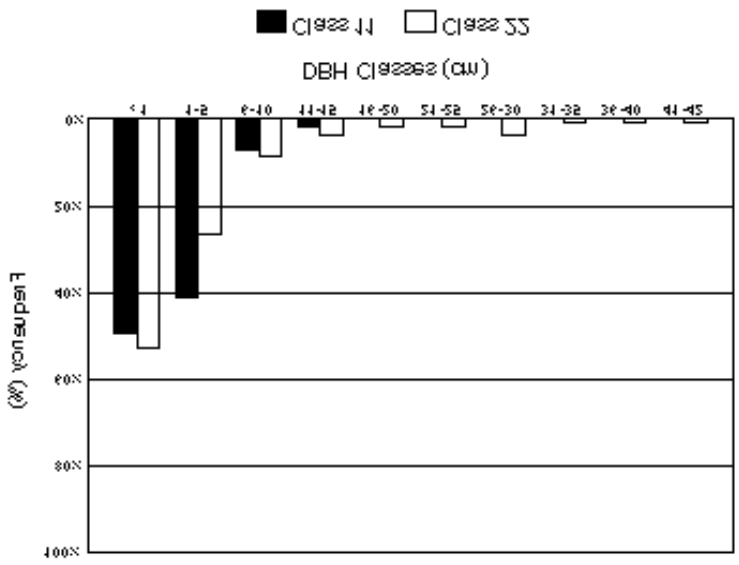


Figure 7. Diameter distribution of the Chulu catchment woodlands.

As with Kamundi the <1cm diameter class is dominated by the forest class rather than the scrub/regeneration woodland. The rest of the Figure 7 follows the expected trend of Class 11 dominating the 1-5cm diameter class and Class 22 dominating the remaining diameter classes.

Table 13. Stems per Hectare of the Two Woodland Classes

Woodland Class	*Stems per hectare*
11	*3,958*
22	*1,167*

Class 11 is too highly stocked and some management will be needed in the near future in order to avoid stagnation of the woodland. Thinning should be carried out in order to release some of the stems.

3.4 Chilindamaji catchment (Nkhata Bay)

Table 14. Woodland Class Descriptions

Class	
1	*Scrub/regeneration woodland*
2	*Forest*

3.4.1. Precision of the results

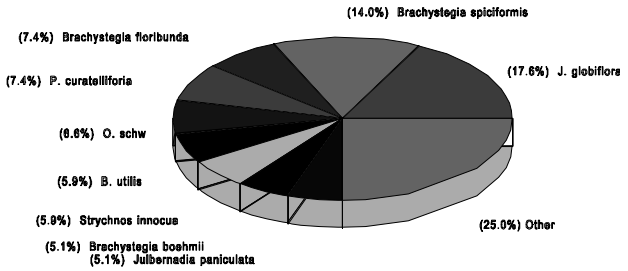
The precision of the plots are presented in Table 15.

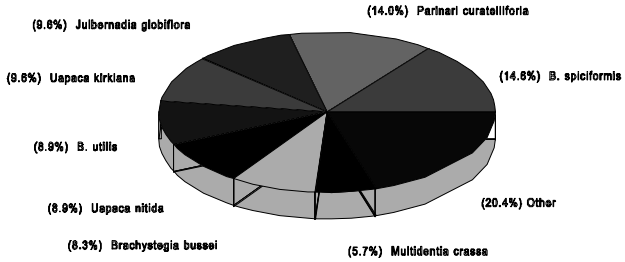
Table 15. Precision of Plots in Chilindamaji Catchment by Woodland Class in Regard to DBH

	Class 1	*Class 2*
DBH	*28.3%*	*42.8%*

3.4.2 Species composition

Both woodlands have some of the most preferred species represented at >5% of the total composition of each woodland (Figures 8 and 9). With the correct management, these and other preferred species can be encouraged in order to aid the local people.





Both of the woodlands in this catchment have a lower diversity of species than the other two catchments (Table 16).

Table 16. Species Diversity within Each Woodland Class of Each Catchment

Catchment	*Woodland class*	*Number of Species (not including unknowns)*
Kamundi	*3*	*30*
	4	*38*
	6	*33*
Chulu	*11*	*38*
	22	*34*
Chilindamaji	*1*	*22*
	2	*23*

3.4.3 End-uses of the woody resource

Table 17. End-Uses within Class 1 Woodlands

Class 1		
small	*2,800*	*42%*
firewood	*1,400*	*21%*
pole	*1,033*	*16%*
fibre	*933*	*14%*
racks	*267*	*4%*
fruits	*233*	*4%*
SUM	*6,667*	*100%*

Table 18. End-Uses within Class 2 Woodlands

Class 2		
firewood	*2,333*	*27%*
small	*1,900*	*22%*
pole	*1,800*	*21%*
fruits	*1,167*	*14%*
fibre	*867*	*10%*
racks	*500*	*6%*
SUM	*8,567*	*100%*

The top three end-uses are dominated by the expected 'small,' 'fuelwood,' and 'poles' categories. Class 2 has a lower proportion in the small category than Class1. This is borne out by the diameter distribution (Section 3.4.4.), which illustrates the proportion of stems in the <1cm diameter class.

Fibre is higher in the scrub/regeneration class than expected due to the preference for small stems for this end-use.

Fruits are more abundant in Class 2, the forest class. Clearly, this is due to the maturer trees in

that class being able to bear fruit.

3.4.4 Diameter distribution and stocking of the woody resource

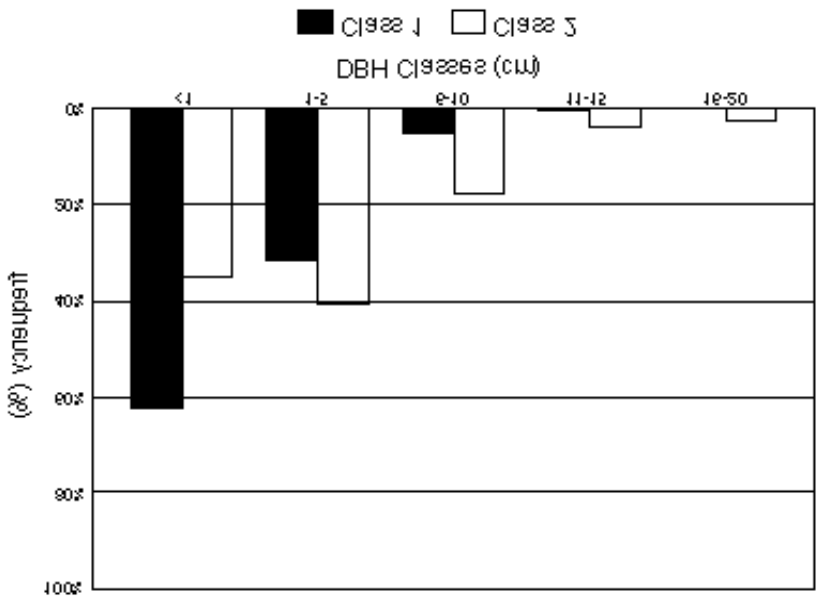


Figure 10. Diameter distribution of the Chilindamaji catchment woodlands.

Both woodlands follow the expected trends. Most of the scrub/regeneration woodland is in the <1cm diameter class, indicating a young woodland with leading stems climbing into the higher diameter classes. There are quite a few seedlings in the forest class. This class in general is still relatively young as none of the stems are greater than 20cm in diameter at breast height.

Table 19. Stems per Hectare of the Two Woodland Classes

Woodland Class	*Stems per hectare*
1	*4,533*
2	*5,233*

Both classes are badly overstocked and are in need of management soon in order to stop the woodlands stagnating and so as to derive the maximum benefit of the woody resource.

4.0 DISCUSSION

From the tables showing the stocking of the woodland areas within the catchments, most of the areas are overstocked and in serious need of management. Overstocking can be relieved by careful thinning of selected species and stems depending upon the objectives of the management. Preferred species can be encouraged to grow by thinning out competition from neighbouring trees. Grasses should be managed to avoid destructive late fires. Early burning is a recognised management technique and can be very effective. Grass competition can also be easily managed by grazing or collection of thatch grass for roofs or by a combination of both.

Many miombo species will coppice readily and by careful management miombo woodlands can regenerate quickly yielding relatively high volumes of small sized wood products. Table 20 shows the preferred species and their ability to coppice and root sucker.

Table 20. Coppicability of Preferred Species

Rank	*Species*	*Coppicability / root suckers* [1]
1	*Julbernadia paniculata*	*vigorous coppice, poor pollarding*
2	*Brachystegia boehmii*	*vigorous coppice and root suckers*
3	*Pseudolachnostylis maprouneifolia*	*coppices straight and well*
4	*Uapaca kirkiana*	*coppices in young plants only, root suckers vigorously*
5	*Julbernadia globiflora*	--
6	*Brachystegia spiciformis*	*vigorous coppice, pollards when young*
7	*Azanza garckeana*	--
8	*Mangifera indica*	--
9=	*Lanea discolor*	*truncheons, root suckers, and coppices readily*
9=	*Bauhinia thonningii*	--
11=	*Diplorhynchus condylocarpon*	*coppices readily and root suckers*
11=	*Brachystegia spp*	*dependent upon species*
13	*Eucalyptus spp*	*dependent upon species*
14=	*Brysocarpus orientalis*	--
14=	*Brachystegia floribunda*	*vigorous coppice and pollard*

[1] *From Management of Miombo by Local Communities : Proceedings of a Workshop for Technical Forestry Staff (1995) edited by Lowore, J.D., Abbot, P.G. and Khofi, C.F. Forestry Research Institute of Malawi and Aberdeen University.*

In order to make the woodlands more productive, it is essential that they be managed properly. Because the land is Common Land, a strong Headperson is needed in order to implement any management strategy.

An important part of management is training. The local populace needs to be educated in the pros

and cons of management and/or non-management of forest areas. Modalities for the management of each area need to be worked out with the local populace in order to allow the people to air their views. This is important if management of woodlands is to be successful. Also they may be able to suggest the most effective ways of managing the areas themselves.

Miombo woodland is generally light-demanding and often responds well to canopy opening. Regeneration comes from coppicing, pollarding, root suckers, seedlings, and suffritices. A variety of silvicultural systems may be used in order to improve the productivity of the woodlands. Three are presented below.

Complete/Simple coppice: *All trees over a selected size (i.e., 5cm DBH) are coppiced. Species may be left if it is known that they coppice poorly.*

The stand is completely opened up. Growth tends to be more vigorous with this system than the others due to the greater amount of light received. Grass competition is greater, however. If properly managed, this grass growth can be used for fodder or thatch as a forest non-wood product. Browsing may be a problem if a large animal population is allowed into the area.

Pollarding reduces this as trees are felled at breast height rather than just above ground level.

This is not suitable on steep slopes due to the erosion factor.

Coppice with Standards: *Most trees (i.e., approx. two thirds) are coppiced/pollarded and the rest are left as standards. This gives a greater diversity of sizes and possibly end-uses. Standards can be selected based on a variety of criteria such as species, form, etc. Standards will supply seed for the area in order to aid regeneration.*

Grass competition is lowered due to the lower level of light reaching the grass layer compared with a complete coppice. Coppice vigour is also slightly reduced.

Selective thinning: *A selected percentage of the canopy is thinned. Some coppicing will normally result depending upon the species felled. Growth is less vigorous for both grass and coppice shoots. This system is more sustainable on steeper slopes, however.*

More studies are needed in order to ascertain the best management plan for each area. The three presented above may not be suitable, and an intermediate regime may be best. Also a greater precision of data is needed before any plan is implemented.

Miombo woodlands can be productive if they are managed carefully. In many places where the miombo woodland has been cleared and eucalypts planted, the miombo has regenerated and outgrown the planted trees. The range of products available from these woodlands is also very diverse. Both wood and non-wood products can be harvested.

The Forestry Research Institute of Malawi (FRIM) is currently carrying out long term studies on the above three management regimes. Three years of data have already been collected, and another three year project is due to carry on the assessments. This will give more accurate indications of the productivity of these systems. Also an inventory of Chimaliro Forest Reserve is planned to give estimates of productivity. A co-management plan is to be drafted with Group Village Boni in Chimaliro in order to promote the sustainable use of the Forest Reserve. Group Village Boni has been used for PRAs for the last three years and village based enumerators are employed to assess the amount of each forest product utilised. This gives valuable information on the needs of the local people and highlights the importance of managing the dwindling resources in the Forest Reserve.

FRIM is also conducting studies on Mangweru Hill near Lunzu in the Southern Region in order to create a working Village Forest Committee and to devise a management plan for the Village Forest Area.

The MEMP PSPs should be re-assessed on a regular basis in order to monitor the productivity/degradation of the woodlands. The number of PSPs need to be increased and they need to be re-assessed at regular intervals in order to gain growth rates of the woodlands and to assess the impact of burley tobacco farming on these woodlands.

The MEMP work has made use of satellite data for mapping the four catchment areas. This mapping technique is extremely useful and should be encouraged where possible. Each of the strata used for this report was mapped separately from the digitized satellite data. The satellite data can be used successively over a number of years to show land use changes over time. Once the ground truthing exercises are completed, effective and economical mapping of Malawi will be feasible.

APPENDIX 1
Species Composition and End-Use Tables for Each Woodland in Each Catchment

Table 21. Species Composition of Class 3 Woodland in the Kamundi Catchment

SPECIES COMPOSITION (CLASS 3)		End-Use No./ha								
SPECIES	No/ha	small	pole	fibre	F.wood	fruits	racks	medicine	rafter	broom
Zanha africana	817	117	167	0	333	0	150	17	0	0
Securidaca longepedunculata	450	150	67	0	133	0	133	0	17	33
Multidentia crassa	300	250	17	0	33	0	0	17	0	0
Catunaregam spinosa	233	117	0	0	83	0	0	50	0	0
Dalbergiella nyasea	217	50	50	0	67	0	17	0	33	0
Vitex payos	200	33	0	0	133	117	0	0	0	0
Julbernadia globiflora	150	17	17	33	83	0	0	0	0	0
Annona senegalensis	133	33	67	0	100	0	17	0	0	0
Flacourtia indica	133	50	0	0	50	0	0	0	0	0
Strychnos spinosa	133	33	33	0	50	33	0	0	0	0
Brachystegia bussei	117	100	0	0	17	0	0	0	0	0
Dalbergia nitidula	100	67	17	0	33	0	0	0	0	0
Psorospermum febrifugum	83	17	33	0	50	0	0	0	0	0
Brachystegia utilis	67	17	33	0	17	0	0	0	0	0
Strychnos cocculoides	67	33	17	0	17	0	0	0	0	0
Brachystegia floribunda	50	17	0	0	17	0	0	0	0	0
Lannea discolor	50	17	0	0	0	0	0	17	0	0
Acacia galpinii	33	33	0	0	0	0	0	0	0	0
Bridelia cathartica	33	0	17	0	33	0	0	0	0	0
Dichrostachys cinerea	33	0	0	0	33	0	0	0	0	0
Pterocarpus rotundifolius	33	0	0	0	33	0	0	0	0	0
Terminalia sericea	33	0	17	0	17	0	0	0	17	0
Acacia nigrensis	17	0	0	0	17	0	0	17	0	0
Brachystegia longifolia	17	17	0	0	0	0	0	0	0	0
Cussonia arborea	17	0	0	0	17	0	0	0	0	0
Diplorhynchus condylocarpon	17	0	0	0	17	0	0	0	0	0
Ochna schweinfurthiana	17	0	0	0	17	0	0	0	0	0
Pseudolachnostylis maprouneifolia	17	0	0	0	17	0	0	0	0	0
Pterocarpus angolensis	17	0	0	0	17	0	17	0	0	0
Strychnos innocua	17	0	0	0	17	0	0	0	0	0
SUM	3,600	1,167	550	33	1,450	150	333	117	67	33

Table 22. Species Composition of Class 4 Woodland in the Kamundi Catchment

SPECIES COMPOSITION (CLASS 4)		End-Use No./ha								
SPECIES	No/ha	small	pole	fibre	firewood	fruits	racks	medicine	rafter	other

Julbernadia globiflora	943	600	57	114	200	0	129	0	0	0
Brachystegia bussei	486	171	143	186	229	0	0	0	14	0
Dalbergiella nyasea	414	300	43	0	71	0	0	0	0	0
Diplorhynchus condylocarpon	243	71	71	0	129	0	0	0	43	0
Bridelia cathartica	157	86	43	0	71	0	0	0	0	0
Dichrostachys cinerea	129	71	0	0	57	0	0	0	0	0
Lannea discolor	114	29	0	0	0	0	0	86	0	0
Brachystegia boehmii	100	57	0	0	43	0	0	0	0	0
Pericopsis angolensis	100	43	14	0	43	0	14	0	0	14
Brachystegia utilis	71	43	29	0	0	0	0	0	0	0
Terminalia sericea	71	0	29	0	71	0	43	0	0	0
Unknown	71	29	0	0	29	0	0	0	0	0
Diospyros kirkii	57	14	0	0	43	0	0	0	0	0
Uapaca nitida	57	29	14	0	29	0	0	0	0	0
Vangueria infausta	57	29	14	0	14	14	14	0	0	0
Annona senegalensis	43	29	14	0	14	0	0	0	0	0
Brachystegia spiciformis	43	29	0	14	0	0	0	0	0	0
Cussonia arborea	43	14	0	0	29	0	0	0	0	0
Dalbergia nitidula	43	29	14	0	14	0	0	0	0	0
Multidentia crassa	43	14	14	0	14	14	0	0	0	0
Pseudolachnostylis maprouneifolia	43	14	0	0	29	0	0	0	0	0
Pterocarpus angolensis	43	0	14	0	29	0	0	0	0	0
Terminalia stenostachya	43	29	14	0	14	0	0	0	0	0
Brachystegia floribunda	29	0	0	14	29	0	0	0	0	0
Ochna schweinfurthiana	29	0	0	0	29	0	0	0	0	0
Turraea nilotica	29	29	0	0	0	0	0	0	0	0
Acacia goetzei	14	14	0	0	0	0	0	0	0	0
Bauhinia thonningii	14	0	0	0	0	0	0	0	0	0
Brachystegia longifolia	14	14	0	0	0	0	0	0	0	0
Combretum molle	14	0	14	0	14	0	0	0	0	0
Dalbergia melanoxylon	14	14	0	0	0	0	0	0	0	0
Faurea saligna	14	0	0	0	14	0	0	0	0	0
Julbernadia paniculata	14	14	0	0	0	0	0	0	0	0
Lonchocarpus capassa	14	0	0	0	0	0	0	0	0	0
Monotes africanus	14	0	14	0	14	0	0	0	0	0
Psorospermum febrifugum	14	14	0	0	0	0	0	0	0	0
Stereospermum kunthianum	14	0	0	0	0	0	0	14	0	0
Zanha africana	14	0	0	0	14	0	0	0	0	0
SUM	3,671	1,829	557	329	1,286	29	200	100	57	14

Table 23. Species Composition of Class 6 Woodland in the Kamundi Catchment

SPECIES COMPOSITION (CLASS 6)									
		End-Use No./ha							
SPECIES	*No/ha*	*small*	*pole*	*fibre*	*firewood*	*fruits*	*racks*	*medicine*	*rafter*
Brachystegia boehmii	325	225	25	42	92	0	0	0	0
Dalbergiella nyasea	175	100	17	0	50	0	17	8	0
Ochna schweinfurthiana	150	42	58	0	108	0	0	0	0
Strychnos spinosa	125	117	0	0	8	0	0	0	0
Brachystegia floribunda	108	58	0	0	42	0	33	0	8
Monotes africanus	108	83	0	0	17	0	25	0	0

Dalbergia nitidula	92	33	8	0	25	0	8	42	8
Pseudolachnostylis maprouneifolia	83	25	25	0	42	0	0	0	0
Brachystegia bussei	75	8	0	0	67	0	0	0	0
Diplorhynchus condylocarpon	75	33	0	8	42	0	0	0	0
Elephantorrhiza goetzei	50	0	0	0	42	0	0	0	0
Parinari curatelliforia	50	17	0	0	8	33	0	0	0
Catunaregam spinosa	33	8	0	0	17	0	0	8	0
Cussonia arborea	33	33	0	0	0	0	0	0	0
Pterocarpus angolensis	33	25	0	0	8	0	0	0	0
Ximenia caffra	33	33	0	0	0	0	0	0	0
Bridelia cathartica	25	17	0	8	8	0	0	0	0
Julbernadia globiflora	25	25	0	0	0	0	0	0	0
Pericopsis angolensis	25	8	0	0	8	0	8	0	0
Burkea africana	17	8	0	0	8	0	8	0	0
Combretum molle	17	17	0	0	0	0	0	0	0
Dichrostachys cinerea	17	8	0	0	8	0	0	0	0
Diospyros kirkii	17	0	8	0	0	0	0	8	0
Flacourtia indica	17	8	0	0	8	0	0	0	0
Lannea discolor	17	8	8	0	8	0	0	0	0
Turraea nilotica	17	17	0	0	0	0	0	0	0
Acacia goetzei	8	8	0	0	0	0	0	0	0
Annona senegalensis	8	8	0	0	0	0	0	0	0
Erythria abyssinica	8	0	0	0	0	0	0	8	0
Pavetta schumanniana	8	8	0	0	0	0	0	0	0
Psorospermum febrifugum	8	0	0	0	8	0	0	0	0
Senna singueana	8	8	0	0	0	0	0	0	0
Uapaca nitida	8	8	0	0	0	0	0	0	0
Unknown	8	0	0	0	0	0	0	0	0
SUM	1,808	1,000	150	58	625	33	100	75	17

Table 24. Species Composition of Class 11 Woodland in the Chulu Catchment

SPECIES COMPOSITION								
		No./ha						
Species	Number	Small	F.wood	Fibre	Poles	Medicine	Gum	Charcoal
Brachystegia floribunda	808	283	250	67	183	42	33	33
Julbernadia paniculata	450	100	158	125	183	117	25	67
Brachystegia boehmii	358	192	92	8	42	50	8	67
Brachystegia utilis	333	50	175	133	133	33	33	0
Brachystegia stipulata	325	83	75	33	133	67	33	33
Faurea speciosa	267	0	200	67	233	33	0	0
Diplorhynchus condylocarpon	233	33	58	42	75	67	0	0
Ochna schweinfurthiana	158	50	42	33	17	33	0	25
Pericopsis angolensis	133	50	50	0	25	42	0	17
Julbernadia globiflora	100	0	33	0	100	67	0	0
Bridelia cathartica	92	42	42	33	42	8	0	0
Flacourtia indica	75	33	33	0	33	8	0	0
Brachystegia spiciformis	75	42	0	33	0	0	0	0
Burkea africana	67	17	8	0	8	42	0	0
Turraea nilotica	42	0	17	0	8	17	0	17
Lannea discolor	33	17	8	8	8	0	0	0
Ximenia caffra	33	0	33	0	33	0	0	0
Dichrostachys cinerea	33	0	17	0	17	17	0	0
Bauhinia thonningii	33	8	8	0	0	0	0	0
Psorospermum febrifugum	33	8	8	8	8	8	0	0
Protea angolensis	25	0	25	0	25	0	0	0
Ochna leotocrada	25	8	8	0	0	0	0	0
Dalbergiella nyasea	25	17	0	8	0	0	0	0
Olax obtusifolia	25	8	17	0	0	0	0	17
Acacia amythe	17	0	8	0	8	0	0	0
Senna singueana	17	0	0	0	0	0	0	0
Multidentia crassa	17	8	8	0	0	0	0	0
Combretum molle	17	0	8	0	8	8	0	0
Strychnos innocua	17	17	0	0	0	0	0	0
Rothmannia englerana	17	17	0	0	0	0	0	0
Brachystegia longifolia	8	0	8	0	8	0	0	0
G.	8	0	8	8	8	0	0	0
Monotes africanus	8	0	0	0	0	0	0	0
V. africana	8	0	8	0	0	0	0	8
Strychnos spinosa	8	8	0	0	0	0	0	0
Catunaregam spinosa	8	0	8	8	8	0	0	0
Pseudolachnostylis maprouneifolia	8	0	0	0	0	8	0	0
Dalbergia nitidula	8	8	0	0	0	0	0	0
Parinari curatelliforia	8	8	0	0	0	0	0	0
SUM	3,958	1,108	1,417	617	1,350	667	133	283

Table 24 (cont'd). Species Composition of Class 11 Woodland in the Chulu Catchment

SPECIES COMPOSITION							
	No/ha						
SPECIES	Racks	Fruits	Carvings	Fishing	Fence	Housewa re	Caterpiiiars
Brachystegia floribunda	42	67	8	17	0	8	0

Julbernadia paniculata	25	0	0	0	0	0	75
Brachystegia boehmii	8	0	0	0	0	8	0
Brachystegia utilis	8	8	0	0	0	0	0
Brachystegia stipulata	0	0	0	0	0	0	33
Faurea speciosa	67	0	0	0	0	0	0
Diplorhynchus condylocarpon	42	8	0	0	0	0	0
Ochna schweinfurthiana	17	8	0	0	0	0	0
Pericopsis angolensis	17	0	0	0	0	0	0
Julbernadia globiflora	0	0	0	0	0	0	0
Bridelia cathartica	0	0	0	0	0	0	0
Flacourtia indica	0	0	0	0	0	0	0
Brachystegia spiciformis	0	0	0	0	0	0	0
Burkea africana	0	0	0	0	0	0	0
Turraea nilotica	0	8	0	0	0	0	8
Lannea discolor	8	0	0	0	0	0	0
Ximenia caffra	0	0	0	0	0	0	0
Dichrostachys cinerea	17	17	0	0	0	0	0
Bauhinia thonningii	8	0	0	0	8	0	0
Psorospermum febrifugum	0	0	0	0	0	0	0
Protea angolensis	0	0	0	0	0	0	0
Ochna leotocrada	17	0	0	0	0	0	0
Dalbergiella nyasea	0	0	0	0	0	0	0
Olax obtusifolia	17	0	0	0	0	0	0
Acacia amythe	0	0	0	0	0	0	0
Senna singueana	17	0	0	0	0	0	0
Multidentia crassa	0	0	0	0	0	0	0
Combretum molle	0	8	0	0	0	0	0
Strychnos innocua	0	0	0	0	0	0	0
Rothmannia englerana	0	0	0	0	0	0	0
Brachystegia longifolia	0	0	0	0	0	0	0
G.	0	0	0	0	0	0	0
Monotes africanus	8	0	0	0	0	0	0
V. africana	0	0	0	0	0	0	0
Strychnos spinosa	0	0	0	0	0	0	0
Catunaregam spinosa	0	0	0	0	0	0	0
Pseudolachnostylis maprouneifolia	0	0	0	0	0	0	0
Dalbergia nitidula	0	0	0	0	0	0	0
Parinari curatelliforia	0	0	0	0	0	0	0
SUM	317	125	8	17	8	17	117

Table 25. Species Composition of Class 22 Woodland in the Chulu Catchment

SPECIES COMPOSITION											
		No./ha									
Species	No.	Small	F. wood	Fibre	Poles	Medicine	Gum	Racks	Latex	Fruits	House-ware
Brachystegia boehmii	167	117	42	33	8	0	0	8	0	0	0
Brachystegia stipulata	158	125	25	0	8	0	0	0	0	0	0
Julbernadia paniculata	100	25	50	0	58	8	8	0	8	8	8
Protea angolensis	75	42	17	8	17	0	0	0	0	0	0
Ochna schweinfurthiana	58	25	33	8	25	0	0	8	0	0	0

Dichrostachys cinerea	50	33	17	0	17	0	0	0	0	0	0
Pseudolachnostylis maprouneifolia	50	17	25	8	17	0	0	0	0	0	0
Bridelia cathartica	50	33	8	8	8	0	0	0	0	0	0
Diplorhynchus condylocarpon	50	50	0	0	0	0	0	0	0	0	0
Ximenia caffra	42	25	17	0	0	0	0	0	0	0	0
Monotes africanus	33	17	8	0	17	8	8	0	0	0	0
Brachystegia floribunda	33	25	0	0	8	0	0	0	0	0	0
Acacia amythe	33	25	8	8	8	0	0	0	0	0	0
Combretum molle	25	8	17	0	0	0	0	0	0	0	0
Multidentia crassa	25	25	0	0	0	0	0	0	0	0	0
Zanha africana	17	8	0	0	0	0	0	0	8	0	0
Burkea africana	17	8	0	8	0	0	0	0	0	0	0
Pleurostylis africana	17	0	8	8	8	0	0	0	8	0	0
Flacourtia indica	17	17	0	0	0	0	0	0	0	0	0
Faurea speciosa	17	8	8	0	0	0	0	0	0	0	0
Rothmannia engierana	17	0	0	8	17	0	0	0	0	0	0
Turraea nilotica	17	8	0	0	0	8	0	0	0	0	0
Combretum zeyheri	8	8	0	0	0	0	0	0	0	0	0
Swartzia madagascariensis	8	8	0	0	0	0	0	0	0	0	0
Zizyphus mucronata	8	0	8	0	0	0	0	0	0	0	0
Brachystegia spiciformis	8	0	8	0	8	0	0	0	0	0	0
Terminalia stenostachya	8	0	8	0	0	0	0	0	0	0	0
Lannea discolor	8	8	0	0	0	0	0	0	0	0	0
Senna singueana	8	0	0	0	0	0	0	0	0	8	0
Pericopsis angolensis	8	0	8	0	8	0	0	0	0	0	0
Diospyros kirkii	8	8	0	0	0	0	0	0	0	0	0
Uapaca nitida	8	8	0	0	0	0	0	0	0	0	0
Brachystegia utilis	8	8	0	0	0	0	0	0	0	0	0
Dalbergia nitidula	8	8	0	0	0	0	0	0	0	0	0
SUM	1,167	700	317	100	233	25	17	17	25	17	8

Table 26. Species Composition of Class 1 Woodland in the Chilindamaji Catchment

SPECIES COMPOSITION									
		No./ha							
Species	Number	small	pole	fibre	F.wood	fruits	racks	medicine	rafter
Julbernadia globiflora	800	467	267	267	300	0	67	0	0
Brachystegia spiciformis	633	300	267	333	333	0	67	0	0
Brachystegia floribunda	333	267	33	33	33	0	0	0	0
Parinari curatelliforia	333	133	200	0	200	167	0	0	0
Ochna schweinfurthiana	300	300	0	0	0	0	0	0	0
Brachystegia utilis	267	167	33	33	67	0	33	0	0
Strychnos innocua	267	167	0	0	67	0	67	0	0
Brachystegia boehmii	233	33	33	167	133	0	0	0	0
Julbernadia paniculata	233	200	33	33	33	0	0	0	0
Diplorhynchus condylocarpon	200	167	33	0	33	0	0	0	0
Multidentia crassa	167	133	0	0	0	0	33	0	0
Brachystegia longifolia	133	33	67	33	33	0	0	0	0
Vitex payos	133	67	0	0	67	33	0	0	0
Combretum molle	100	100	0	0	0	0	0	0	0
Dalbergia nitidula	100	67	33	0	33	0	0	0	0
Bridelia micrantha	67	67	0	0	0	0	0	0	0
Pericopsis angolensis	67	33	0	33	33	0	0	0	0
Dalbergiella nyasea	33	33	0	0	0	0	0	0	0
Rothmannia englerana	33	33	0	0	0	0	0	0	0
Stereospermum kunthianum	33	0	33	0	0	0	0	0	0
Syzygium guineense	33	0	0	0	33	33	0	0	0
Uapaca nitida	33	33	0	0	0	0	0	0	0
SUM	4,533	2,800	1,033	933	1,400	233	267	0	0

Table 27. Species Composition of Class 2 Woodland in the Chilindamaji Catchment

SPECIES COMPOSITION									
		No./ha							
Species	Number	small	pole	fibre	F.wood	fruits	racks	medicine	rafter
Brachystegia spiciformis	767	367	333	367	333	0	33	0	0
Parinari curatelliforia	733	33	200	0	500	600	67	0	0
Julbernadia globiflora	500	300	100	133	67	0	67	0	0
Uapaca kirkiana	500	100	333	0	367	333	0	0	0
Brachystegia utilis	467	100	233	267	267	0	67	0	0
Uapaca nitida	467	300	100	0	33	0	33	0	0
Brachystegia bussei	433	267	67	33	33	0	67	0	0
Multidentia crassa	300	133	33	0	100	167	0	0	0
Olax obtusifolia	133	0	100	0	133	0	33	0	0
Pericopsis angolensis	133	33	33	0	33	0	33	0	0
Rothmannia englerana	133	100	0	0	33	0	0	0	0
Vitex payos	133	0	67	0	100	0	0	0	0
Unknown	100	33	0	0	33	0	0	0	0
Brachystegia boehmii	67	0	33	33	33	0	0	0	0
Bridelia micrantha	67	0	33	0	67	33	33	0	0
Combretum molle	67	33	0	0	0	0	33	0	0
Dalbergia nitidula	67	33	0	0	33	0	33	0	0
Diospyros zombensis	67	33	33	33	33	0	0	0	0
Allophylus africanus	33	0	33	0	0	0	0	0	0
Bauhinia thonningii	33	0	33	0	33	0	0	0	0
Brachystegia longifolia	33	33	0	0	0	0	0	0	0
Bridelia cathartica	33	0	0	0	33	0	0	0	0
Erythria abyssinica	33	0	0	0	33	0	0	0	0
Ficus natalensis	33	0	33	0	33	33	0	0	0
SUM	**5,233**	**1,900**	**1,800**	**867**	**2,333**	**1,167**	**500**	**0**	**0**

MALAWI ENVIRONMENTAL MONITORING PROGRAM

Report on the Socio-Economic Survey

DRAFT: MAY 1996

Peter A. Walker

Harvard Institute for International Development

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1. Introduction

This report presents the preliminary analysis of the MEMP socio-economic survey, which was carried out in August 1995. The survey enumerated a broad range of socio-economic conditions in smallholder households who farmed fields (either burley tobacco or other crops) in the MEMP catchment areas. The survey collected basic household data to facilitate analysis of (a)how burley tobacco production among smallholder farmers is affecting household economic conditions, (b) the ways that broader socio-economic conditions are affecting the adoption of burley production among smallholders, and (b) the consequences for the use of natural resources.

The analysis presented in this report covers several of the topics identified by MEMP staff as having particular relevance to current interests and concerns of the project. However, the issues discussed herein by no means exhaust the topics of analysis that can be pursued using the data collected in the socio-economic survey. More detailed information on household demographics, patterns of migration and settlement, crop production, food security, landholdings, income strategies, and resource management are available in the database.

This document focuses on patterns of agricultural production, relative wealth of burley growers, food security, land acquisition and fallowing, and use of forest products. Overall, the findings in the survey appear to confirm previous assessments of the relationships between burley production and smallholder wealth, food security, and resource management. In general, burley growers tend to be the wealthier smallholders who are more secure in their food supplies, and who are least likely to face serious problems of resource scarcity. The survey does not reveal major recent changes in overall patterns of agricultural production, although many former burley growers appear to have stopped this year, mainly due to problems related to shortages of fertilizer. Moreover, the survey suggests that overall patterns of land acquisition are similar for burley and non-burley households, although there appears to be a positive association between greater wealth and acquisition of land through the husband's family. Although patterns of acquisition are generally similar, patterns of land use do appear to differ, with burley growers typically leaving less land fallow than non-burley households. Burley growers also have a particularly high demand for certain wood products, especially poles for constructing burley drying sheds.

The survey consisted of a questionnaire administered to 120 households in four MEMP catchments: Kamundi (Mangochi), Njolomole (Ntcheu), Chulu (Kasungu), and Chilindamaji (Nkhata Bay). Wherever possible, the interview was conducted with both the head of the household present as well as his or her spouse. The sample included 60 households that were initially identified as smallholders who grew burley in the 1994-95 season, who held any fields (including crops other than burley) in the MEMP catchments. An equal number of non-burley-growing households was selected randomly for purposes of comparison. Two of the households that were initially identified as burley growers had in fact ceased to grow burley this year, and were recoded as non-burley-growers. Thus, the sample consists of 58 burley growing households and 62 non-burley households. The survey was conducted by a team of four research assistants from the Centre for Social Research at the University of Malawi, and was administered by the Harvard Institute for International Development (HIID).

2. Patterns of agricultural production

Most smallholder farmers in Malawi, including burley growers, pursue a strategy of diversified agricultural production, which includes combinations of hybrid and local maize, cassava, sunflower, legumes, vegetables, fruits, and tobacco. Most of these crops can be used for both home consumption and for cash sales. The impact of burley production on smallholder household economy must be considered in light of ongoing efforts by smallholders to maintain diversified production. None of the smallholder burley growers in the MEMP survey engage solely in burley production, and most allocate only a portion of their available land and capital to burley production. Thus, burley represents only one among a number of strategies for generating income even among burley growers. There is no clear evidence of a shift toward increased allocation of resources to burley production. Although more research is needed, there is some evidence of decreasing interest in burley production, particularly as a result of recent steep increases in fertilizer prices.

2.1 Burley as a source of smallholder income

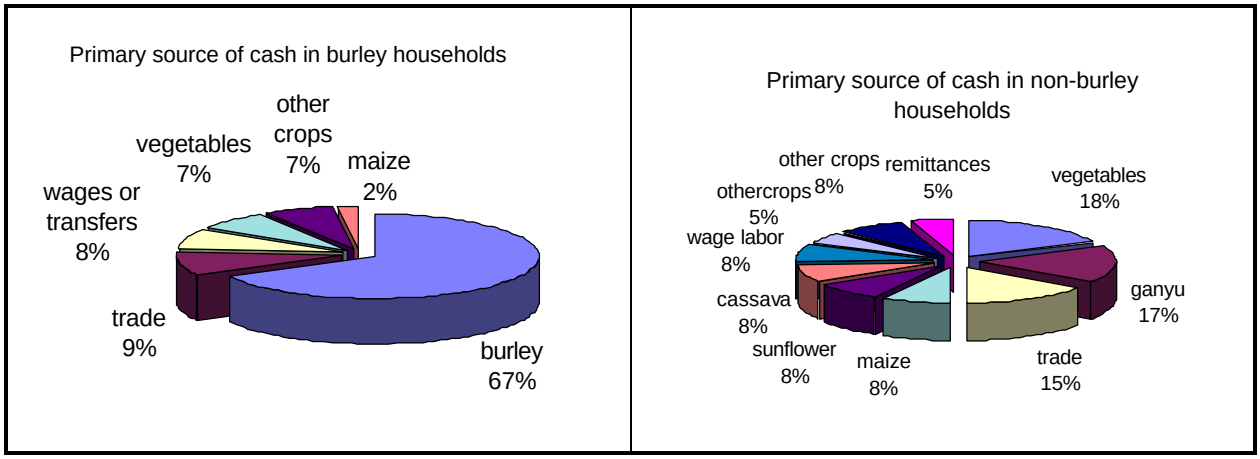

Figure 1. Primary sources of household income across surveyed households.

Burley is an important source of cash for those smallholder farmers who grow it, but it is not the only source (Figure 1). In the MEMP socio-economic survey, smallholders were asked to identify the most important sources of income in their households, and to rank these in relation to each other. Among those who grew burley, two-thirds (67 percent) identified it as their most important source of cash income. The other third of burley growers identified burley as being less important as source of cash than maize or vegetables (Table 1). The relative importance of burley also appears to vary across catchments. In three of the four catchments, burley was reported as the primary source of cash among burley growers. The exception was Njolomole, where sales of vegetables were most frequently cited as the primary source of cash even in burley growing households. Burley was reported as the most important source of cash by only 22 percent of Njolomole burley growers (Table 2). Among non-burley-growing households, sales of vegetables, temporary agricultural labor (*ganyu*), and sales of other crops were identified as the most important source of household income.

2.2 Land allocation

It is important to stress that while burley is the most important source of cash income, it is not necessarily the main source of livelihood even among burley growers. All burley growers in the MEMP sample also grew maize (or, in Nkhata Bay, cassava) as a food staple, as well as combinations of legumes, tubers, vegetables, and fruits.

This fact is reflected in the distribution of smallholder land among a number of crops. Measurements of individual fields and plots are not available, so it is not possible to reliably assess what proportion of land area smallholder burley growers devote to burley production. However, the MEMP socio-economic survey enumerated the number of fields and plots held by smallholders, and which crops were grown in each. These data support the qualitative impression of the HIID survey team that for the most part smallholder burley growers only allocate a portion of their land (and, presumably, labor) to burley production. On average, respondents in the survey hold 2.3 fields, and a total of at least[1] 3.4 individual plots (that is, about half of all fields are subdivided into plots in which different crops such as burley or maize are grown; Table 3). Burley-growing households hold an average of 2.5 fields and 4.1 plots; of these plots, an average of 1.1 are devoted to burley production, compared to 1.5 plots devoted to maize production (Table 4). This gives weight to the qualitative assessment of the HIID team that burley production does not generally take priority over food production in smallholder livelihood strategies.

2.3 Indications of change in burley production

There is little evidence that a large number of smallholders are shifting into burley production, and there are reasons to believe that the number of smallholder burley growers is unlikely to expand significantly under present conditions of increasing fertilizer prices and the collapse and abuse of some burley clubs. The MEMP socio-economic survey recorded a number of non-burley growers who had previously grown burley but stopped because of problems related to credit and fertilizer. A very high proportion of those identified as burley growers in 1994-95 had begun only this past season (Table 5), and in the Njolomole site only a handful of the farmers who were recorded as growing burley in 1993-94 also grew it in 1994-95, suggesting a high rate of failure and turnover among smallholder burley growers.

The reasons for failure in burley growing mainly involve problems of fertilizer and credit, although poor rains have also played a part. Smallholders complained that burley clubs (which are intended to provide credit for inputs, particularly fertilizer) had collapsed due to non-payment of debts and because of disputes over the distribution of profits from sales at auction floors. These problems were recorded in 1994 at Njolomole, and continue to represent a significant barrier to

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[1] Plots recorded in the survey as containing pigeon peas, various types of beans, and groundnuts were not included in calculating the number of individual plots. This is because these crops are frequently intercropped with maize, and therefore it is likely that many of these recorded 'plots' are in reality the same as the plots as those containing maize. In some cases, these crops may be planted in their own plots and not intercropped with maize. By presuming that these are intercrops, the estimation of the number of fields is probably somewhat conservative.

participation in burley production. At Chulu, a very large number of farmers who were identified as having started burley nurseries in the Fall 1994 planting season ended up harvesting no burley at all because of the failure of local clubs to provide fertilizer on terms that were acceptable to local farmers.[2] The number of farmers who attempted and failed in their efforts to grow burley in the Chulu catchment possibly exceeds the number who succeeded. In all catchments, people also complained about unpredictable rainfall. In addition, the recent removal of fertilizer subsidies has put purchases of fertilizer beyond the reach of even relatively wealthy smallholders. Despite these problems, smallholder interest in burley production remains high, especially following the relatively good prices of the last season. But without improved access to credit and/or lower fertilizer prices, the number of smallholders growing burley is likely to remain limited.

3. Burley production and relative smallholder wealth

3.1 Relation between burley growing and smallholder wealth

Smallholder farmers who grow burley are, on the whole, wealthier than non-burley growers. Using the HIID wealth index based on enumeration of household assets, a statistically significant difference is found between burley and non-burley households (significant at the 3.7 percent confidence level; Table 6). This relationship is demonstrated by the predominance of non-burley households (70 percent) in the lowest wealth quartile, whereas most of the wealthiest smallholders (63 percent) are burley growers. In the mid-level wealth quartiles, households are equally likely to be burley or non-burley growers (Table 7). Thus, while burley growing is not always associated with greater wealth, there is a clear and statistically significant tendency for burley production to be associated with relative affluence among smallholders.

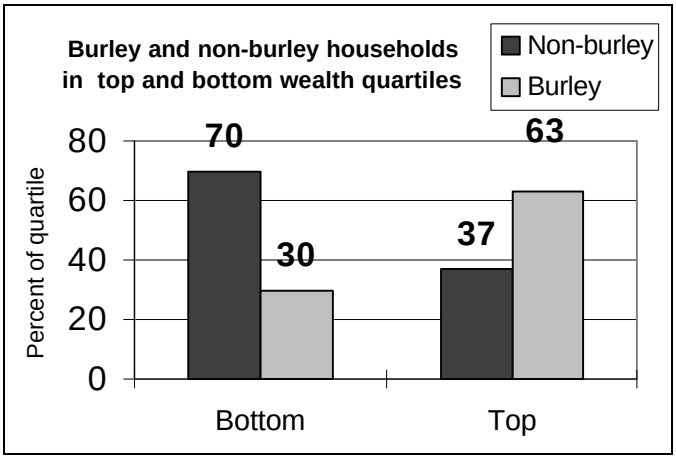

Figure 2. Wealth quartiles for all surveyed households.

[2] The MEMP field assistant in Chulu reports that many borrowers were required to pay 30 percent of the value of the loan plus a 100 kwacha registration fee to enter the club.

3.2 Interpreting the relationship between wealth and burley-growing

The finding that wealth is statistically related to burley growing is not surprising, given considerable qualitative evidence that burley growers are generally among the wealthiest of smallholder farmers. However, the statistics say little about the nature of this relationship. In the absence of baseline socio-economic data collected before the MEMP households began to grow tobacco, it is not possible to definitively answer whether smallholder burley growers became wealthy because they grew burley, or whether they grew burley because they were already wealthy. Qualitative assessment, from both the MEMP socio-economic survey and from other socio-economic analyses, suggests that both interpretations may be true. For the most part, the poorest smallholders are unable or unwilling to invest substantial resources in the potentially lucrative but risky practice of burley cultivation. There is some evidence (particularly in the Chulu and Njolomole catchments) that considerable numbers of poorer smallholders actually were made worse off by investing in failed burley production. However, among those who succeeded in growing burley, many volunteered to the HIID team that their economic conditions have improved because of burley. Thus, it would appear that generally it is the smallholders in the middle and upper economic quartiles who are most likely to grow burley, and that some portion of these find that burley has contributed to increased wealth.

3.3 Relation between burley production and wealth in individual catchments

The relationship between burley production and relatively greater wealth among smallholders is present in three out of the four MEMP catchments (Table 8). The one exception to this trend is the Njolomole site. (Notably, when Njolomole is dropped from the analysis of variance significance test, the significance of the positive relationship between burley production and wealth increases to a level of 0.15 percent; Table 9.)

Finding the exact reasons for this contradictory trend in Njolomole would require more in-depth field work. However, several unusual circumstances may be involved. First, there appears to be a pattern of patron-client burley production between a local estate owner and 7 out of 13 of the burley growers in the Njolomole area. Relatively poor smallholders receive credit for fertilizer from Mr. Thawatha, a local estate owner. Mr. Thawatha then buys the burley from the smallholders and sells it on the auction floors. Several smallholders complained that Mr. Thawatha “cheats” them by not giving them a fair return on their tobacco sales. Another cause of the negative relationship between wealth and burley production is the continuing problems of the burley clubs in this area, which have broken down due to previous failures to pay back credit. In addition, the Ntcheu area has a very active trade in vegetables for urban markets, and a large portion of the wealthiest farmers in the area turn to vegetables, rather than tobacco, for earning cash. Thus, the combination of the availability of private credit to poor farmers for burley production, the breakdown of clubs, and the availability of a more attractive option for earning cash among wealthier smallholders may be making burley production relatively more attractive to poorer farmers and less attractive to wealthier farmers than in other areas.

3.4 Comparing overall wealth in the four catchments

Overall, the four MEMP catchments are generally comparable in their level of wealth. As estimated by the HIID wealth index, the Chilindamaji catchment is recorded as the wealthiest, followed by Chulu, Ntcheu, and Kamundi (Table 10). The relative wealth of the Chilindamaji catchment may be related to the local availability of cash income through fishing. Similarly, the wealth of Chulu may be related to the generally high level of wealth in the Kasungu area due to the dominance of estate tobacco in the local economy

4. Food security

Burley production does not appear to be strongly related to household food production. Overall, households in the MEMP sample, excluding Chilindamaji (see below), produced an average of 249 kilograms per capita of their own maize (Table 11). Burley growers grew slightly more maize than non-burley households (Table 12), though this difference is not statistically significant (Table 13).

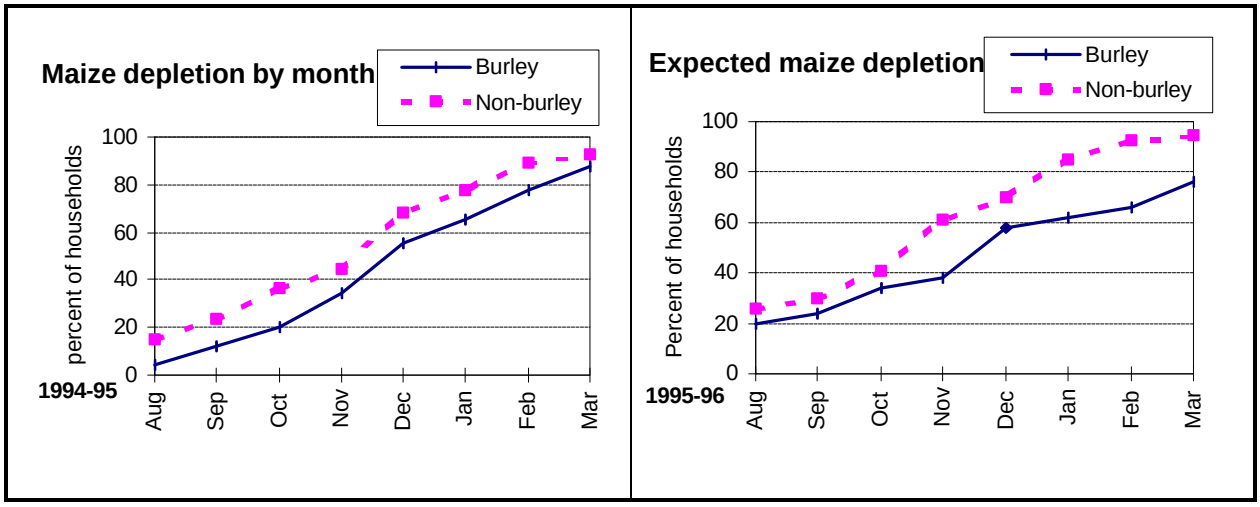

Figure 3. Maize stores across all surveyed households.

Own maize production, however, is not the same thing as food security. Smallholders also buy and sell maize. Because of their greater income, burley producers are presumably in a better position to buy maize. The effect of burley production on maize sales is, however, uncertain. These issues are beyond the scope of the MEMP socio-economic survey. In both the 1994-95 and 1995-96 seasons, burley households reported that they ran out or expect to run out of their own-produced maize later in the season, and a higher proportion of burley households report having purchased maize or expect to buy maize, presumably reflecting their greater disposable income (Table 14; Figure 3).

The Chilindamaji catchment was excluded from the present analysis of food security because smallholders in the Nkhata Bay area generally rely more heavily on cassava than on maize. This makes comparisons of food security between Chilindamaji and the other catchments analytically difficult. This is particularly true because there is no reliable way to estimate cassava production.

Unlike maize, cassava is harvested on an on-going basis throughout the year, and it is rarely stored in a central location such as the *nkhokwe* (granary) typically used to store maize. More commonly, smallholders harvest small amounts of cassava and eat it directly from the field, making reliable estimation of annual harvests exceedingly difficult.

5. Land acquisition

Most fields held by smallholders in the MEMP catchment areas are acquired through the husband's family, the village head, or the wife's family. Other sources include borrowed land, land given by friends or neighbors, land that is rented, and land that is newly opened (Table 15; Figure 4). This pattern appears to vary by catchment, with land acquired through the wife's family being particularly important in Njolomole, and less so in Kamundi. No fields were acquired through the wife's family in either of the northern catchments in Kasungu and Chilindamaji (Table 16).[3] There also appears to be a positive association between both wealth and burley production and acquisition of land through the husband's family (Tables 17 and 18). Among households in the lower two wealth quartiles, one-third of all fields were acquired through the wife's family, compared to less than 7 percent of fields in the upper wealth groups. In the upper wealth groups (hence among burley growers), 85 percent of fields are acquired through the husband's family or through village headmen. The reasons for these associations remain to be explored, but it is likely that these at least in part reflect the greater overall wealth in the two northern catchments, where no fields were acquired through the wife's family.

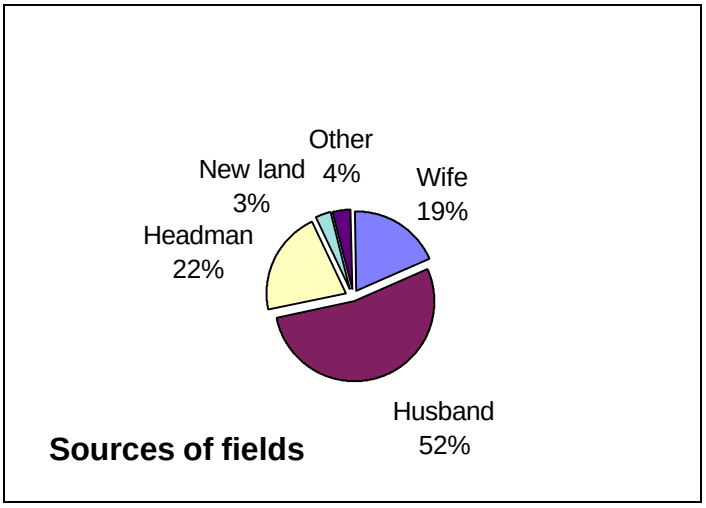

Figure 4. Land acquisition across all households.

[3] Although the Chulu catchment is in Kasungu district, which is populated largely by the matrilineal Chewa people, the catchment itself lies in the northern part of the district where the Tumbuka pattern of patrilineal land inheritance dominates.

6. Fallow fields

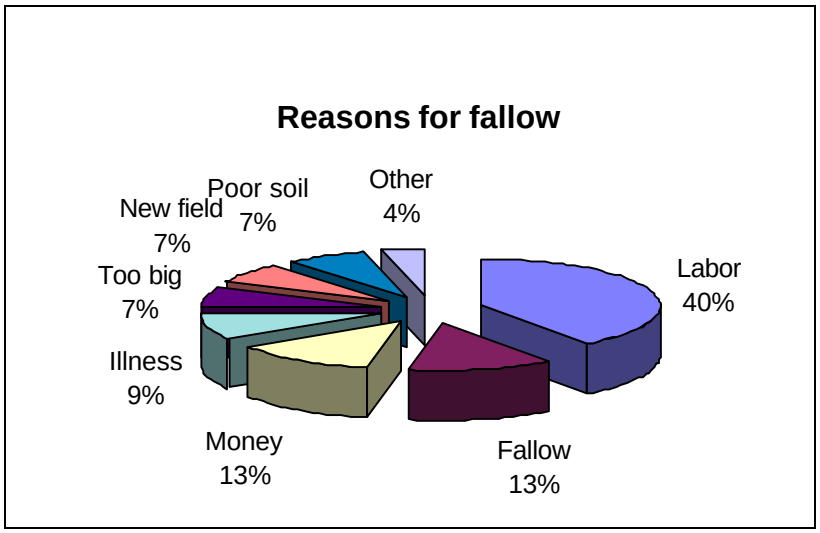

Figure 5. Reasons for allowing fields to remain fallow.

One somewhat surprising finding of the MEMP socio-economic survey is that a substantial number of fields held by smallholder households are left fallow – 45 out of 273 total fields in the survey, or 16 percent. Without having area calculations for these fields, it is not possible to assess what proportion of acreage this represents. Nevertheless, this is surprising considering the general scarcity of land in Malawi, particularly in the south. However, the MEMP survey also shows that the primary reasons for leaving land fallow are shortage of labor, money, or illness (Table 19; Figure 5). Only 13 percent of fields are left fallow for the main purpose of re-generating soil quality. Moreover, the other reasons that smallholders reported for leaving fields fallow include the fact that the fields are "too big" to cultivate completely, the fields are newly acquired, and that the quality of the fields is poor. These factors all in turn relate back to shortages of labor or capital to invest in fully cultivating fields.

The importance of labor and capital shortages as a reason for fallowing land may explain the general tendency for burley-growers (who are wealthier and in a better position to purchase labor) to leave a somewhat lower proportion of their fields (15 percent) fallow than non-burley growers (19 percent). Generally, the reasons that burley growers reported for leaving fields fallow are similar to those of non-burley households, although burley growers were the only people who cited poor quality of soil as a primary reason for not cultivating fields (Table 20). This may relate to the high nutrient demands of tobacco plants. Across catchments, the reasons cited for not cultivating fields are generally similar, with the main reasons being shortages of labor and capital, although the small number of fallow fields when divided across four catchments makes any quantitative assessment somewhat tentative (Table 21).

7. Forest products utilization inventory

The HIID socio-economic survey team combined efforts with the Department of Forestry in carrying out the Forest Products Utilization Inventory (Annex 2). This inventory enumerated the main uses of forest products, the preferred species for each type of use, perceptions of scarcity, and actions taken in response to declining availability of forest products.

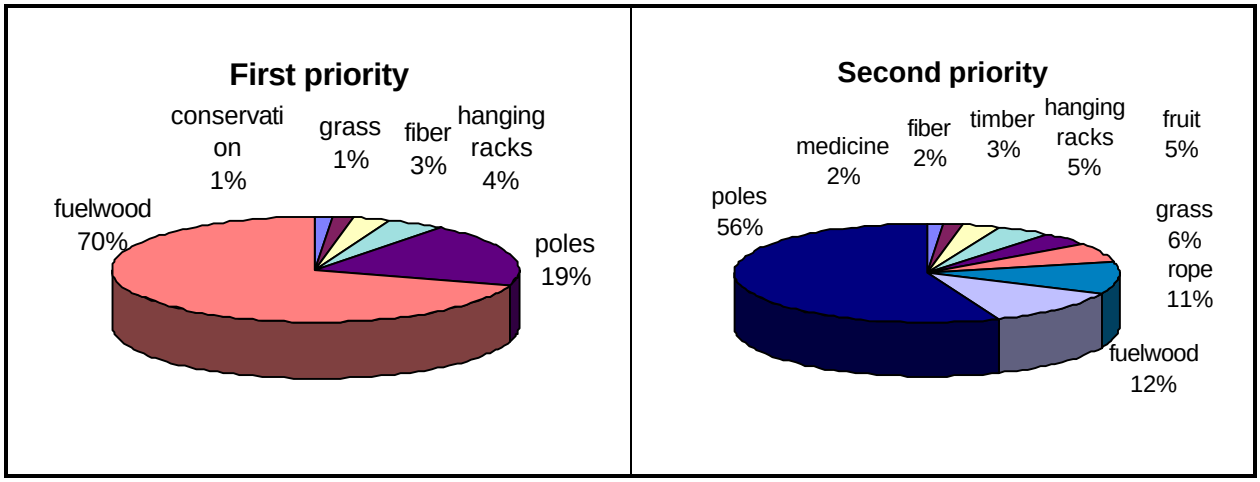

Figure 6. Priority uses for forest products.

Respondents were asked to identify the most important products that they get from local woodlands in order of priority (Figure 6). Respondents often identified as many as half a dozen priority uses. Burley and non-burley households shared very similar priorities, with fuelwood being the overwhelming first priority, and poles being the dominant second priority. Rope, fiber, poles, and timber were the most frequently identified third-priority uses. Other uses identified in each level of priority include hanging racks for tobacco sheds, grass, fruit, medicine, and conservation (Table 22).

The MEMP socio-economic survey recorded a very large number of preferred species for each type of forest product (Table 23). Overall, 134 separate species were recorded.[4] In tabulating the total number of "preferred" species for all uses, there are no species that account for more than about 9 percent of the total number of responses. However, some of the most widely mentioned species include *mtondo*, *msolo*, *muwanga*, *kamphoni*, *msuku*, and *mpapa*. Similarly, for specific wood uses there were no species that were mentioned as being the single most important. For fuelwood, for example, *mtondo* (20 percent of responses), *chiombo* (7.9 percent) and *kamphoni* (7.9 percent) were identified as the most widely preferred species, although another 52 species were recorded as preferred species for fuelwood. Likewise, for poles the most commonly cited preferred species include *msolo* (10.5 percent) and *muwanga* (7.5 percent), although another 64 species were recorded as being preferred for poles (Table 24). Notably, although a few people

[4] This may somewhat overestimate the number, since species were identified by local names, which may differ in each catchment. Some species may have been therefore recorded as separate, when in fact they only have different local names.

did mention *eucalyptus* and other exotics, these species are not among the most preferred for any of the most important forest products identified by smallholders in the MEMP catchments.

Tables

Table 1. Primary Source of Income by Burley, Non-Burley Households

-> burley= 0 (no)

income1	Freq.	Percent	Cum.
maize sales	5	8.33	8.33
sunflower 7	5	8.33	16.67
cassava	5	8.33	25.00
beans	1	1.67	26.67
tomatoes	1	1.67	28.33
vegetables	11	18.33	46.67
other tobac.	1	1.67	48.33
other crop	2	3.33	51.67
sell beer	1	1.67	53.33
fish monger	2	3.33	56.67
other retail	2	3.33	60.00
grass,fwd,et	2	3.33	63.33
artisan	2	3.33	66.67
non-ag labor	5	8.33	75.00
estate labor	2	3.33	78.33
ganyu	10	16.67	95.00
remittances	3	5.00	100.00
Total	60	100.00	

-> burley= 1 (yes)

income1	Freq.	Percent	Cum.
maize	1	1.82	1.82
beans	1	1.82	3.64
tomatoes	1	1.82	5.45
vegetables	4	7.27	12.73
bananas	1	1.82	14.55
burley	37	67.27	81.82
other crop	1	1.82	83.64
selling beer	1	1.82	85.45
selling fish	1	1.82	87.27
grass,fwd,et	1	1.82	89.09
artisan	2	3.64	92.73
non-ag labor	1	1.82	94.55
ganyu	1	1.82	96.36
got rent	1	1.82	98.18
remittances	1	1.82	100.00
Total	55	100.00	

Table 2. Primary Source of Income in Burley Households in Each Catchment

```
-> burley=      yes  catchmnt= Kamundi
     income1|      Freq.     Percent        Cum.
------------+-----------------------------------
tomatoes    |          1        4.55        4.55
burley      |         18       81.82       86.36
other crops |          1        4.55       90.91
non-ag labor|          1        4.55       95.45
remittances |          1        4.55      100.00
------------+-----------------------------------
      Total |         22      100.00

-> burley=      yes  catchmnt= Njolomole
     income1|      Freq.     Percent        Cum.
------------+-----------------------------------
beans       |          1       11.11       11.11
vegetables  |          3       33.33       44.44
burley      |          2       22.22       66.67
brewing beer|          1       11.11       77.78
artisan     |          1       11.11       88.89
ganyu       |          1       11.11      100.00
------------+-----------------------------------
      Total |          9      100.00

-> burley=      yes  catchmnt= Chulu
     income1|      Freq.     Percent        Cum.
------------+-----------------------------------
maize       |          1        5.56        5.56
vegetables  |          1        5.56       11.11
bananas     |          1        5.56       16.67
burley      |         12       66.67       83.33
fish monger |          1        5.56       88.89
artisan     |          1        5.56       94.44
got rent    |          1        5.56      100.00
------------+-----------------------------------
      Total |         18      100.00

-> burley=      yes  catchmnt= Chilindamaji
     income1|      Freq.     Percent        Cum.
------------+-----------------------------------
burley      |          5       83.33       83.33
grass,fwd,et|          1       16.67      100.00
------------+-----------------------------------
      Total |          6      100.00
```

Table 3. Number of Fields and Plots

Variable	Obs	Mean	Std. Dev.	Min	Max
fields	120	2.275	1.180817	0	6
plots	120	3.433333	2.172143	0	12
brlyplts	53	1.09434	.2950978	1	2
maizplts	113	1.513274	.6958428	1	5

Table 4. Number of Fields and Plots by Burley, Non-Burley Households

-> burley= 0

Variable	Obs	Mean	Std. Dev.	Min	Max
fields	62	2.080645	1.135109	0	6
plots	62	2.854839	1.880415	0	10
brlyplts	1	2	.	2	2
maizplts	58	1.517241	.7312901	1	5

-> burley= 1

Variable	Obs	Mean	Std. Dev.	Min	Max
fields	58	2.482759	1.202941	1	6
plots	58	4.051724	2.305009	1	12
brlyplts	52	1.076923	.2690691	1	2
maizplts	55	1.509091	.6631219	1	3

Table 5. When Households First Started Growing Burley

-> burley=1

Years growing burley	Freq.	Percent	Cum.
1	17	29.31	29.31
2	6	10.34	39.66
3	22	37.93	77.59
4	5	8.62	86.21
5	6	10.34	96.55
8	1	1.72	98.28
12	1	1.72	100.00
Total	58	100.00	

Table 6. Association of Wealth and Burley Production

```
Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      583926.327      1   583926.327      4.46     0.0369
 Within groups      15457317.4    118   130994.215
------------------------------------------------------------------------
    Total           16041243.7    119   134800.367
```

Table 7. Burley Production by Wealth Quartiles

```
-> Wealth quartile=1 (poorest)
      burley|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         21       70.00       70.00
          1 |          9       30.00      100.00
------------+-----------------------------------
      Total |         30      100.00

-> Wealth quartile=2
      burley|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         15       50.00       50.00
          1 |         15       50.00      100.00
------------+-----------------------------------
      Total |         30      100.00

-> Wealth quartile=3
      burley|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         15       50.00       50.00
          1 |         15       50.00      100.00
------------+-----------------------------------
      Total |         30      100.00

-> Wealth quartile=4
      burley|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         11       36.67       36.67
          1 |         19       63.33      100.00
------------+-----------------------------------
      Total |         30      100.00
```

Table 8. Burley by Wealth in Individual Catchments

```
-> catchmnt=Kamundi  burley=0
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      22         268        200         49        887

-> catchmnt=Kamundi  burley=1
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      22         457        421         46       1841

-> catchmnt=Njolomole  burley=0
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      15         477        602         47       2479

-> catchmnt=Njolomole  burley=1
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      11         341        205        133        781

-> catchmnt=Chulu  burley=0
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      18         331        282         13        941

-> catchmnt=Chulu  burley=1
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      18         548        383        103       1881

-> catchmnt=Chilindamaji  burley=0
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |       7         303        174         22        536

-> catchmnt=Chilindamaji  burley=1
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |       7         597        304        317       1214
```

Table 9. Significance Test for Burley Production and Wealth without Njolomole

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      1090807.19      1   1090807.19     10.75     0.0015
 Within groups      9332888.13     92   101444.436
------------------------------------------------------------------------
    Total           10423695.3     93   112082.745
```

Table 10. Wealth by Catchment

```
-> catchmnt=Kamundi
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      44         362        340         46       1841

-> catchmnt=Njolomole
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      26         419        474         47       2479

-> catchmnt=Chulu
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      36         440        349         13       1881

-> catchmnt=Chilindamaji
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
  assets |      14         450        283         22       1214
```

Table 11. Overall Maize Production (kg)

```
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
pcmzprod |     103    248.8932   278.5632          0       1556
```

Table 12. Maize Production by Burley, Non-Burley Household (kg)

```
-> burley=        0
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
pcmzprod |      54    241.7963   306.9275          0       1556

-> burley=        1
Variable |     Obs        Mean   Std. Dev.       Min        Max
---------+-----------------------------------------------------
pcmzprod |      49    256.7143   246.4915         10       1266
```

Table 13. Significance Test for Relationship between Burley and Maize Production

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      5717.06598      1   5717.06598      0.07     0.7876
 Within groups      7909224.76    101    78309.156
------------------------------------------------------------------------
    Total           7914941.83    102   77597.4689
```

Table 14. Maize Purchases in Burley, Non-Burley Households

```
-> burley=        0
    bghtmaiz|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         32       59.26       59.26
          1 |         22       40.74      100.00
------------+-----------------------------------
      Total |         54      100.00

-> burley=        1
    bghtmaiz|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         21       42.00       42.00
          1 |         29       58.00      100.00
------------+-----------------------------------
      Total |         50      100.00

1994-95 Households who expect to buy maize

-> burley=        0
    bghtmaiz|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         16       29.63       29.63
          1 |         38       70.37      100.00
------------+-----------------------------------
      Total |         54      100.00

-> burley=        1
    bghtmaiz|      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |         11       22.45       22.45
          1 |         38       77.55      100.00
------------+-----------------------------------
      Total |         49      100.00
```

Table 15. Sources of Land

```
. tabulate sourcecd
    sourcecd|      Freq.     Percent        Cum.
------------+-----------------------------------
wife’s famil|         49       19.14       19.14
husband’s fa|        132       51.56       70.70
chief       |         56       21.88       92.58
borrowed    |          4        1.56       94.14
neighbors   |          3        1.17       95.31
rented      |          2        0.78       96.09
new land    |          8        3.12       99.22
other       |          2        0.78      100.00
------------+-----------------------------------
      Total |        256      100.00
```

Table 16. Land Sources by Catchment

-> catchmnt= Kamundi

sourcecd	Freq.	Percent	Cum.
wife’s famil	20	25.32	25.32
husband’s fa	29	36.71	62.03
chief	26	32.91	94.94
borrowed	3	3.80	98.73
other	1	1.27	100.00
Total	79	100.00	

-> catchmnt= Njolomole

sourcecd	Freq.	Percent	Cum.
wife’s famil	29	50.00	50.00
husband’s	23	39.66	89.66
chief	2	3.45	93.10
borrowed	1	1.72	94.83
neighbors	1	1.72	96.55
rented	2	3.45	100.00
Total	58	100.00	

-> catchmnt= Chulu

sourcecd	Freq.	Percent	Cum.
husband’s fa	56	67.47	67.47
chief	17	20.48	87.95
neighbors	2	2.41	90.36
new land	8	9.64	100.00
Total	83	100.00	

-> catchmnt= Chilindamaji

sourcecd	Freq.	Percent	Cum.
husband’s fa	24	66.67	66.67
chief	11	30.56	97.22
neighbors	1	2.78	100.00
Total	36	100.00	

Table 17. Land Sources by Wealth Ranking

-> mempgrup= 1 (poorest)

sourcecd	Freq.	Percent	Cum.
wife's famil	10	17.54	17.54
husband's fa	28	49.12	66.67
chief	16	28.07	94.74
borrowed	1	1.75	96.49
new land	2	3.51	100.00
Total	57	100.00	

-> mempgrup= 2

sourcecd	Freq.	Percent	Cum.
wife's famil	30	48.39	48.39
husband's	16	25.81	74.19
chief	12	19.35	93.55
borrowed	2	3.23	96.77
rented	2	3.23	100.00
Total	62	100.00	

-> mempgrup= 3

sourcecd	Freq.	Percent	Cum.
wife's famil	6	9.23	9.23
husband's fa	40	61.54	70.77
chief	11	16.92	87.69
borrowed	1	1.54	89.23
neighbors	2	3.08	92.31
new land	5	7.69	100.00
Total	65	100.00	

-> mempgrup= 4 (wealthiest)

sourcecd	Freq.	Percent	Cum.
wife's famil	3	4.17	4.17
husband's fa	48	66.67	70.83
chief	17	23.61	94.44
neighbors	1	1.39	95.83
new land	1	1.39	97.22
other	2	2.78	100.00
Total	72	100.00	

Table 18. Land Sources by Burley, Non-Burley Households

-> burley= 0

sourcecd	Freq.	Percent	Cum.
wife's famil	31	25.62	25.62
husband's fa	61	50.41	76.03
chief	17	14.05	90.08
borrowed	2	1.65	91.74
neighbors	1	0.83	92.56
rented	2	1.65	94.21
new land	5	4.13	98.35
other	2	1.65	100.00
Total	121	100.00	

-> burley= 1

sourcecd	Freq.	Percent	Cum.
wife's famil	18	13.33	13.33
husband's fa	71	52.59	65.93
chief	39	28.89	94.81
borrowed	2	1.48	96.30
neighbors	2	1.48	97.78
new land	3	2.22	100.00
Total	135	100.00	

Table 19. Reasons for Fallowing Fields

ynotcode	Freq.	Percent	Cum.
fallow	6	13.33	13.33
illness, etc	4	8.89	22.22
money	6	13.33	35.56
labor	18	40.00	75.56
too big	3	6.67	82.22
new field	3	6.67	88.89
poor soil	3	6.67	95.56
other	2	4.44	100.00
Total	45	100.00	

Table 20. Reasons for Fallow by Burley, Non-Burley Households

-> burley= 0

ynotcode	Freq.	Percent	Cum.
fallow	3	12.50	12.50
illness, etc	4	16.67	29.17
money	2	8.33	37.50
labor	11	45.83	83.33
too big	1	4.17	87.50
new field	2	8.33	95.83
other	1	4.17	100.00
Total	24	100.00	

-> burley= 1

ynotcode	Freq.	Percent	Cum.
fallow	3	14.29	14.29
money	4	19.05	33.33
labor	7	33.33	66.67
too big	2	9.52	76.19
new field	1	4.76	80.95
poor soil	3	14.29	95.24
other	1	4.76	100.00
Total	21	100.00	

Table 21. Reasons for Fallow by Catchment

-> catchmnt= Kamundi

ynotcode	Freq.	Percent	Cum.
fallow	1	5.26	5.26
illness, etc	1	5.26	10.53
money	4	21.05	31.58
labor	8	42.11	73.68
too big	3	15.79	89.47
new field	1	5.26	94.74
other	1	5.26	100.00
Total	19	100.00	

-> catchmnt= Njolomole

ynotcode	Freq.	Percent	Cum.
illness, etc	1	12.50	12.50
money	2	25.00	37.50
labor	1	12.50	50.00
new field	1	12.50	62.50
poor soil	2	25.00	87.50
other	1	12.50	100.00
Total	8	100.00	

-> catchmnt= Chulu

ynotcode	Freq.	Percent	Cum.
fallow	2	20.00	20.00
illness, etc	2	20.00	40.00
labor	6	60.00	100.00
Total	10	100.00	

-> catchmnt= Chilindamaji

ynotcode	Freq.	Percent	Cum.
fallow	3	37.50	37.50
labor	3	37.50	75.00
new field	1	12.50	87.50
poor soil	1	12.50	100.00
Total	8	100.00	

Table 22. Uses of Forests in Order of Importance

```
-> rank=        1
     wooduse|      Freq.     Percent        Cum.
------------+-----------------------------------
conservation|          1        1.49        1.49
fuelwood    |         47       70.15       71.64
grass       |          1        1.49       73.13
hanging rack|          3        4.48       77.61
poles       |         13       19.40       97.01
rope fiber  |          2        2.99      100.00
------------+-----------------------------------
      Total |         67      100.00

-> rank=        2
     wooduse|      Freq.     Percent        Cum.
------------+-----------------------------------
fuelwood    |          8       12.12       12.12
grass       |          4        6.06       18.18
hanging rack|          3        4.55       22.73
poles       |         37       56.06       78.79
rope fiber  |          7       10.61       89.39
fiber       |          1        1.52       90.91
medicine    |          1        1.52       92.42
timber      |          2        3.03       95.45
fruit       |          3        4.55      100.00
------------+-----------------------------------
      Total |         66      100.00

-> rank=        3
     wooduse|      Freq.     Percent        Cum.
------------+-----------------------------------
fuelwood    |          5        8.62        8.62
grass       |          5        8.62       17.24
hanging rack|          3        5.17       22.41
poles       |          8       13.79       36.21
rope fiber  |         18       31.03       67.24
fiber       |          8       13.79       81.03
medicine    |          3        5.17       86.21
timber      |          7       12.07       98.28
fruit       |          1        1.72      100.00
------------+-----------------------------------
      Total |         58      100.00

-> rank=        4
     wooduse|      Freq.     Percent        Cum.
------------+-----------------------------------
fuelwood    |          3        6.82        6.82
grass       |          6       13.64       20.45
hanging rack|          8       18.18       38.64
poles       |          3        6.82       45.45
rope fiber  |          7       15.91       61.36
fiber       |          3        6.82       68.18
medicine    |          2        4.55       72.73
timber      |          1        2.27       75.00
fruit       |         11       25.00      100.00
------------+-----------------------------------
      Total |         44      100.00
```

Table 23. Preferred Species

```
. tabulate specode
     specode|      Freq.     Percent        Cum.
------------+-----------------------------------
      bamba |          3        0.70        0.70
     bamboo |          2        0.47        1.16
```

bluegum	4	0.93	2.09
bthomnin	1	0.23	2.33
chigwene	2	0.47	2.79
chikabal	1	0.23	3.02
chiombo	37	8.60	11.63
chithowi	9	2.09	13.72
chitimbe	3	0.70	14.42
chiyere	1	0.23	14.65
chothoui	1	0.23	14.88
cyprus	1	0.23	15.12
eucalypt	5	1.16	16.28
g. arbor	1	0.23	16.51
jombo	1	0.23	16.74
kabvenje	3	0.70	17.44
kachere	2	0.47	17.91
kalama	3	0.70	18.60
kalikuku	1	0.23	18.84
kamemena	7	1.63	20.47
kamphoni	15	3.49	23.95
kamphoye	1	0.23	24.19
kamsuni	2	0.47	24.65
kamvenje	1	0.23	24.88
kapirapi	1	0.23	25.12
kasokolo	1	0.23	25.35
katope	3	0.70	26.05
kavwenje	1	0.23	26.28
kawidzi	3	0.70	26.98
kuvwenje	2	0.47	27.44
libvungw	1	0.23	27.67
lopo	4	0.93	28.60
lulunga	1	0.23	28.84
m'banga	1	0.23	29.07
m'bawa	2	0.47	29.53
mango	13	3.02	32.56
masuku	4	0.93	33.49
mateme	1	0.23	33.72
matomo	1	0.23	33.95
matowo	2	0.47	34.42
mavuvu	1	0.23	34.65
mawula	1	0.23	34.88
maye	1	0.23	35.12
mazaye	4	0.93	36.05
mbanga m	10	2.33	38.37
mbawa	1	0.23	38.60
mbovu	3	0.70	39.30
mbula	4	0.93	40.23
mbuluka	1	0.23	40.47
mbuwa	2	0.47	40.93
mbuzi	1	0.23	41.16
mchenga	6	1.40	42.56
mchiwa	1	0.23	42.79
mfutu	1	0.23	43.02
mikuti	2	0.47	43.49
miseza	1	0.23	43.72
misolo	1	0.23	43.95
mitondo	3	0.70	44.65
miwanga	2	0.47	45.12
miyumbu	1	0.23	45.35
mkalakat	1	0.23	45.58
mkulu	1	0.23	45.81
mkuti	8	1.86	47.67
mkuyu	1	0.23	47.91
mlemba	2	0.47	48.37
mlombwa	2	0.47	48.84
mngotoka	1	0.23	49.07
mnjoyi	1	0.23	49.30
mombo	2	0.47	49.77

mpalapal	1	0.23	50.00
mpapa	11	2.56	52.56
mpapaden	2	0.47	53.02
mphatwe	1	0.23	53.26
mpululu	2	0.47	53.72
msani	3	0.70	54.42
msekese	8	1.86	56.28
msendalu	1	0.23	56.51
msokolow	3	0.70	57.21
msolo	20	4.65	61.86
msuku	12	2.79	64.65
msumbu	8	1.86	66.51
mthethe	1	0.23	66.74
mtondo	40	9.30	76.05
mtowa	3	0.70	76.74
mtowo	2	0.47	77.21
mtwana	1	0.23	77.44
mukuti	2	0.47	77.91
mulombwa	2	0.47	78.37
mumwa	1	0.23	78.60
musawi	1	0.23	78.84
musokolo	1	0.23	79.07
musu	1	0.23	79.30
musuku	2	0.47	79.77
musumba	1	0.23	80.00
muswenje	1	0.23	80.23
muula	2	0.47	80.70
muvukwe	1	0.23	80.93
muwanga	20	4.65	85.58
muwemba	1	0.23	85.81
muwuwa	2	0.47	86.28
mvukwe	5	1.16	87.44
mwaphe	4	0.93	88.37
mwuwa	2	0.47	88.84
n'chakat	2	0.47	89.30
naliusui	1	0.23	89.53
naphini	1	0.23	89.77
nemena	1	0.23	90.00
ng'ona	1	0.23	90.23
ngowe	1	0.23	90.47
njombo	1	0.23	90.70
nkaziwam	1	0.23	90.93
nsindra	1	0.23	91.16
nsolo	3	0.70	91.86
nthema	1	0.23	92.09
nthombod	2	0.47	92.56
nthudza	1	0.23	92.79
nthumbuz	1	0.23	93.02
nyozi	1	0.23	93.26
palibeka	1	0.23	93.49
phuliphu	2	0.47	93.95
pomapro	1	0.23	94.19
sokolo	1	0.23	94.42
strychno	1	0.23	94.65
termi.se	1	0.23	94.88
thedza	2	0.47	95.35
thithion	1	0.23	95.58
thombozi	5	1.16	96.74
tsamba	5	1.16	97.91
tsemba	1	0.23	98.14
tsimba	1	0.23	98.37
u. kirki	4	0.93	99.30
usendalu	1	0.23	99.53
utomoni	1	0.23	99.77
yembe	1	0.23	100.00
Total	430	100.00	

Table 24. Preferred Species by Use

-> prodcode= fiber

specode	Freq.	Percent	Cum.
chiombo	2	10.53	10.53
chithowi	2	10.53	21.05
jombo	1	5.26	26.32
kamphoni	1	5.26	31.58
mbanga m	2	10.53	42.11
mchenga	2	10.53	52.63
mkulu	1	5.26	57.89
mkuti	1	5.26	63.16
mombo	1	5.26	68.42
mpapa	1	5.26	73.68
msani	1	5.26	78.95
mvukwe	1	5.26	84.21
mwaphe	1	5.26	89.47
thithion	1	5.26	94.74
tsamba	1	5.26	100.00
Total	19	100.00	

-> prodcode= fruit

specode	Freq.	Percent	Cum.
kasokolo	1	2.94	2.94
mango	10	29.41	32.35
masuku	3	8.82	41.18
matomo	1	2.94	44.12
matowo	2	5.88	50.00
mavuvu	1	2.94	52.94
mawula	1	2.94	55.88
maye	1	2.94	58.82
mazaye	3	8.82	67.65
mbula	2	5.88	73.53
mbuluka	1	2.94	76.47
mbuwa	1	2.94	79.41
msuku	3	8.82	88.24
nthema	1	2.94	91.18
nthudza	1	2.94	94.12
nthumbuz	1	2.94	97.06
u. kirki	1	2.94	100.00
Total	34	100.00	

-> prodcode=fuelwood

specode	Freq.	Percent	Cum.
bamba	1	0.71	0.71
bluegum	1	0.71	1.43
chigwene	1	0.71	2.14
chikabal	1	0.71	2.86
chiombo	11	7.86	10.71
chithowi	4	2.86	13.57
chitimbe	2	1.43	15.00
chothoui	1	0.71	15.71
cyprus	1	0.71	16.43
eucalypt	2	1.43	17.86
g. arbor	1	0.71	18.57
kabvenje	1	0.71	19.29
kachere	1	0.71	20.00
kamphoni	11	7.86	27.86
kamphoye	1	0.71	28.57
kamvenje	1	0.71	29.29
kavwenje	1	0.71	30.00

```
   kuvwenje |          1        0.71       30.71
      mango |          3        2.14       32.86
     mazaye |          1        0.71       33.57
   mbanga m |          5        3.57       37.14
      mbawa |          1        0.71       37.86
      mbovu |          1        0.71       38.57
      mbula |          1        0.71       39.29
    mchenga |          2        1.43       40.71
     mikuti |          2        1.43       42.14
     miseza |          1        0.71       42.86
    mitondo |          2        1.43       44.29
   mkalakat |          1        0.71       45.00
      mkuti |          5        3.57       48.57
      mombo |          1        0.71       49.29
      mpapa |          7        5.00       54.29
      msani |          2        1.43       55.71
    msekese |          2        1.43       57.14
      msolo |          1        0.71       57.86
      msuku |          1        0.71       58.57
     msumbu |          4        2.86       61.43
    mthethe |          1        0.71       62.14
     mtondo |         28       20.00       82.14
      mtowa |          1        0.71       82.86
      mtowo |          1        0.71       83.57
     mukuti |          2        1.43       85.00
    musumba |          1        0.71       85.71
   muswenje |          1        0.71       86.43
    muvukwe |          1        0.71       87.14
    muwanga |          5        3.57       90.71
     mvukwe |          4        2.86       93.57
   n'chakat |          1        0.71       94.29
      ngowe |          1        0.71       95.00
     njombo |          1        0.71       95.71
      nyozi |          1        0.71       96.43
     thedza |          1        0.71       97.14
     tsamba |          2        1.43       98.57
     tsemba |          1        0.71       99.29
      yembe |          1        0.71      100.00
------------+-----------------------------------
      Total |        140      100.00

-> prodcode=   poles
     specode|      Freq.     Percent        Cum.
------------+-----------------------------------
    bluegum |          3        2.26        2.26
   bthomnin |          1        0.75        3.01
   chigwene |          1        0.75        3.76
    chiombo |          2        1.50        5.26
   chitimbe |          1        0.75        6.02
   eucalypt |          3        2.26        8.27
   kabvenje |          1        0.75        9.02
     kalama |          3        2.26       11.28
   kalikuku |          1        0.75       12.03
   kamemena |          5        3.76       15.79
   kamphoni |          1        0.75       16.54
    kamsuni |          1        0.75       17.29
     katope |          3        2.26       19.55
    kawidzi |          2        1.50       21.05
   kuvwenje |          1        0.75       21.80
       lopo |          4        3.01       24.81
    m'banga |          1        0.75       25.56
     masuku |          1        0.75       26.32
   mbanga m |          3        2.26       28.57
      mbovu |          1        0.75       29.32
      mbula |          1        0.75       30.08
      mbuwa |          1        0.75       30.83
      mbuzi |          1        0.75       31.58
```

```
    mchenga |          2        1.50       33.08
     mchiwa |          1        0.75       33.83
    miwanga |          1        0.75       34.59
    miyumbu |          1        0.75       35.34
     mlemba |          2        1.50       36.84
     mnjoyi |          1        0.75       37.59
      mpapa |          2        1.50       39.10
    mphatwe |          1        0.75       39.85
    mpululu |          2        1.50       41.35
    msekese |          4        3.01       44.36
   msendalu |          1        0.75       45.11
      msolo |         14       10.53       55.64
      msuku |          5        3.76       59.40
     msumbu |          1        0.75       60.15
     mtondo |          5        3.76       63.91
      mtowa |          2        1.50       65.41
      mtowo |          1        0.75       66.17
     mtwana |          1        0.75       66.92
      mumwa |          1        0.75       67.67
   musokolo |          1        0.75       68.42
     musuku |          2        1.50       69.92
    muwanga |         10        7.52       77.44
     muwuwa |          1        0.75       78.20
     mwaphe |          1        0.75       78.95
      mwuwa |          2        1.50       80.45
   n'chakat |          1        0.75       81.20
    naphini |          1        0.75       81.95
     nemena |          1        0.75       82.71
     ng'ona |          1        0.75       83.46
    nsindra |          1        0.75       84.21
      nsolo |          2        1.50       85.71
   nthombod |          2        1.50       87.22
   phuliphu |          2        1.50       88.72
    pomapro |          1        0.75       89.47
     sokolo |          1        0.75       90.23
   strychno |          1        0.75       90.98
   termi.se |          1        0.75       91.73
     thedza |          1        0.75       92.48
   thombozi |          4        3.01       95.49
     tsamba |          1        0.75       96.24
     tsimba |          1        0.75       96.99
   u. kirki |          3        2.26       99.25
    utomoni |          1        0.75      100.00
------------+-----------------------------------
      Total |        133      100.00

-> prodcode=    rope
     specode|      Freq.     Percent        Cum.
------------+-----------------------------------
      bamba |          2        4.65        4.65
    chiombo |         21       48.84       53.49
   chithowi |          3        6.98       60.47
   kabvenje |          1        2.33       62.79
    kachere |          1        2.33       65.12
   kamphoni |          2        4.65       69.77
      mbovu |          1        2.33       72.09
    mitondo |          1        2.33       74.42
      mkuti |          2        4.65       79.07
      mpapa |          1        2.33       81.40
     mtondo |          2        4.65       86.05
     musawi |          1        2.33       88.37
     mwaphe |          2        4.65       93.02
      nsolo |          1        2.33       95.35
     tsamba |          1        2.33       97.67
   usendalu |          1        2.33      100.00
------------+-----------------------------------
      Total |         43      100.00
```

MALAWI ENVIRONMENTAL MONITORING PROGRAM

REPORT AND FIELD GUIDELINES:
RAINFALL, RUNOFF, SEDIMENT TRANSPORT, AND WATER-QUALITY MONITORING ACTIVITIES

CHILINDAMAJI CATCHMENT

Bisher Imam, Ph.D.
Department of Hydrology and Water Resources
The University of Arizona

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Glossary

abstract	$I + C$
BOD	Biological Oxygen Demand.
C	The amount of rainfall intercepted by plants.
CN	The curve number coefficient in the SCS-CN method.
CN_e	The estimated average curve number.
CN_i	The computed curve number for the ith runoff producing event.
EPA	United States Environmental Protection Agency.
ET	Evapotranspiration.
HHZ	The Hawkins-Hejlmfelt-Zevenbergen approach for estimating CNs.
i	The rainfall event (storm) counter.
I	Water infiltration into soil.
I_a	The initial abstraction
MEMP	Malawi Environmental Monitoring Program.
MoREA	Ministry of Research and Environmental Affairs.
n	The total number of runoff producing events.
NPSP	Nonpoint Source Pollution.
P	Precipitation (for conditions in Malawi, equivalent to rainfall).
P_e	Deep percolation into soil.
PSP	Point Source Pollution.
Q	The total daily runoff volume.
Q_{ei}	The estimated runoff for each rainfall event.
R	Surface runoff.
S	Soil water storage
S	The maximum potential difference between P and Q at the beginning of a storm.
SCS-CN	The U.S. Soil Conservation Service Curve Number method.
S_e	Estimated soil water storage.
S_i	Lateral subsurface inflow into soil.
SM	Soil moisture.
S_o	Lateral subsurface outflow from soil.
USAID	United States Agency for International Development.
AMC	Antecedent moisture conditions.
USDA	United States Department of Agriculture.
USLE	The Universal Soil Loss Equation.
A	The USLE sediment yield.
R	The USLE rainfall-runoff erosivity index.
K	The USLE soil-erodibility factor.
L	The USLE length-of-slope factor.
S	The USLE degree-of-slope factor.
C	The USLE crop-management factor.
P	The USLE conservation-practice factor.
e_m	The kinetic energy of the mth intensity period for a unit rainfall.
i_m	The rainfall intensity period energy.
E_m	The total kinetic energy for the intensity period.
I_{30}	The maximum 30-minute rainfall intensity.
EI	The total kinetic energy of a storm.
i_m	The rainfall intensity for the mth period.
Pe_m	The cumulative rainfall at the end of the mth period.

Ps_m	The cumulative rainfall at the start of the *m*th period.
te_m	The time at the end of the *m*th period.
ts_m	The time at the start of *m*th period.
a	Percent soil organic matter
b	The soil structure code.
c	The soil profile permeability class.
SF	The soil structure factor.
TF	The soil texture factor.
PF	The soil permeability factor.
M	The soil texture parameter.
l	The slope length.
q	The slope angle.
m	The slope steepness parameter.
SPHA	The soil-plant-hydrosphere-atmosphere system.
$\overline{S_i}$	The *i*th event running average storage parameter.
S_j	The *j*th event storage parameter.
MOE	A Multiple-Objective Evaluation.
Sed.	Soil sediment loss.
TDS	Total Dissolved Solids
WQDSS	The USDA Water Quality Decision Support System.

1. Introduction

1.1. Background

The United Sates Agency for International Development [USAID] and the government of Malawi are collaborating to provide the Malawi Environmental Monitoring Program [MEMP] with the necessary field, technical, and analytical training to carry out several environmental monitoring activities. MEMP was initiated to fulfill a threefold mission aimed at assisting the Ministry of Research and Environmental Affairs [MoREA] and other departments to:

1. Monitor the environmental impacts of policy reforms, in particular the impacts of smallholders' production of burley tobacco;
2. Establish a national capability to assess, monitor, and manage the environmental resources of Malawi; and
3. Provide equipment, training, and methods necessary for the fast and efficient production of maps, documents, and reports based on the results of MEMP's environmental monitoring activities.

To fulfill the above objectives, MEMP has been conducting monitoring programs in five small catchments near Nkhata Bay, Chikwawa, Dowa, Mangochi, and Kassungu (Figure 1). The monitoring activities include water sampling at catchment outlets, installation of erosion control-plots and pits, field monitoring pits, and the installation of automated samplers at two of the above-mentioned locations.

Although MEMP is a newly established program, it has the potential to become an integral part of the decisionmaking process at the level of national agricultural policy as well as at the level of operational farm-management. MEMP's capabilities can be enhanced through a combination of well-planned pilot data collection campaigns, training activities, scientific collaborations, and publications.

Providing the necessary training in the area of evaluating the environmental impacts of farm practices is at the heart of MEMP's objectives, and this report represents an effort in that direction. However, because the existing environmental record is too short to comprehensively evaluate and characterize the environmental impacts of different practices, this report concentrates on establishing guidelines for data analysis rather than providing policy recommendations. The report will attempt to make maximum use of the data collected from several erosion control-plots and field pits for the purpose of illustrating procedures such as (a) the identification of empirical rainfall-runoff relationships, (b) quality control and reduction of data, and (c) statistical analyses. Scientific and conceptual principals will be briefly illustrated, emphasizing operational aspects such as unit conversion, criteria-based selection of acceptable datasets, and data requirements for different environmental assessment objectives.

1.2. Environmental Impacts of Nonpoint Source Pollution

Environmental pollution of surface and ground water resources is classified as being either point source pollution [PSP] or nonpoint source pollution [NPSP]. PSP is defined as a concentrated effluent discharge at a given point. Examples of PSP include leakage from fuel tanks into groundwater, sewage effluent discharge into a lake or a stream, and other identifiable and usually measurable sources. On the other hand, NPSP is associated with the natural transport of dissolved and suspended materials carried by overland flow of storm water and/or irrigation water into streams and within porous soils. Major sources of NPSP include sediment, nutrients, pesticides, carbonaceous biological oxygen demand [BOD], nitrogenous BOD, and pathogens.

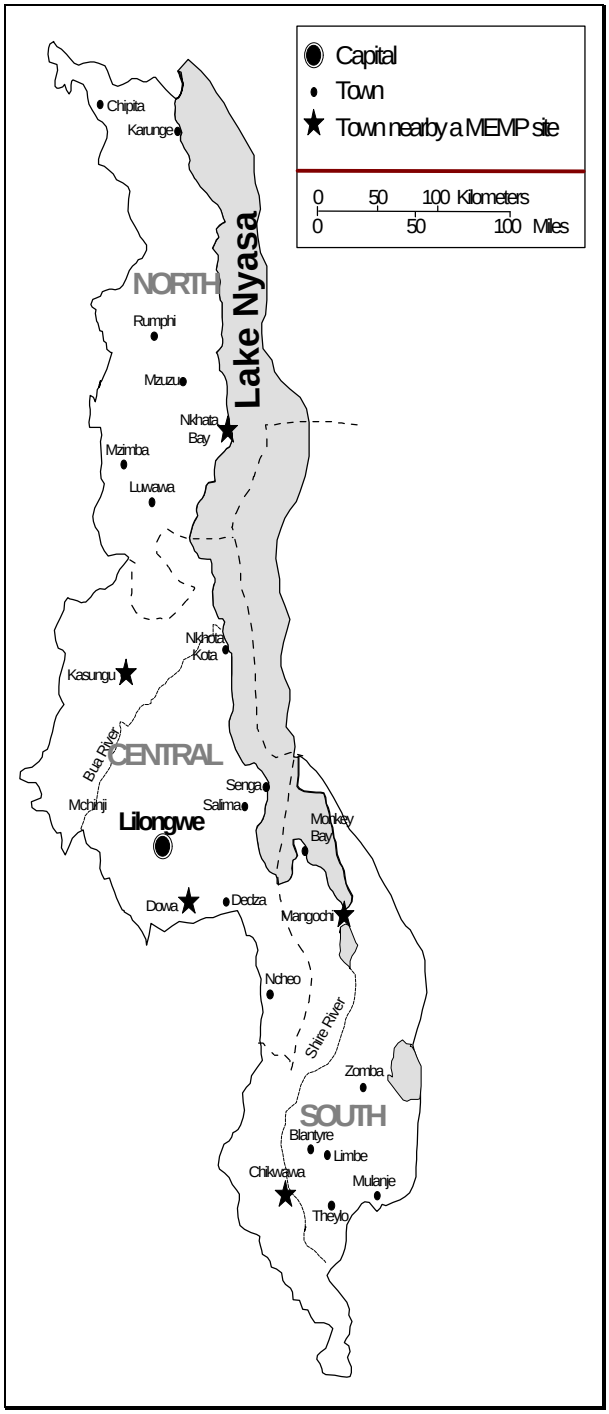


Figure 1. Map of Malawi depicting the locations of MEMP monitoring sites. Note that the sites are distributed in all three regions of the country (north, central, and south).

Transport and loading of nonpoint source pollutants have been occurring since geological times due to natural processes. However, transport and loading rates can be accelerated or decelerated by human activities that modify the natural properties of the watershed, thereby affecting the driving processes. Countless examples of the impacts of agricultural activities on the rate of erosion, nutrient loading, and pesticide loading can be found around the world. In 1991, The United States Environmental Protection Agency [EPA] has identified agriculturally-derived NPSP loading into surface water as *the* major cause of

river and stream impairment in the continental U.S. In Malawi, erosion-caused siltation has reduced the effective head above the turbine from 6 m to 3 m in the Lower Shire River. Whether agricultural activities are responsible for the erosion can only be answered by quantifying and comparing the rate of erosion from different management systems.

Soil and nutrient losses have both on-site and off-site impacts. On-site impacts exist within the boundary of the field and/or the watershed, and include loss of productivity, soil degradation, and increased salinity. The economic loss associated with these impacts can be very high. For example, Pimental et al. (1995) reported that an estimated 4 billion tons of soil are lost from U.S. cropland each year. Furthermore, an estimated 1 million ha of cropland are lost each year in developing nations. The cost of associated on-site nutrient losses in the U.S. reaches $20 billion/year; another $7 billion/year is the estimated cost of lost soil.

Off-site impacts represent the consequences of (a) runoff mediated sediment discharge, nutrient loading, and pesticides loading of surface streams, and (b) chemical loading of groundwater via infiltration and deep percolation. Eutrophication of surface-water bodies is the most critical off-site impact of nutrient transport, and occurs as a direct result of excessive nutrient concentrations in the water body. Eutrophication significantly reduces dissolved oxygen, and eventually leads to the extinction of aquatic life in the water body. In addition to the degradation of water quality, the deposition of sediments can lead to the reduction of water storage capacities in watercourses and reservoirs. Termed "stream siltation," this can (a) cause an increase in the frequency and magnitude of floods, and (b) blanket the stream-bottom gravel beds necessary for the reproduction of some fish species.

Because of the significant adverse economic and environmental impacts of NPSP as well as the high costs of erosion control and abatement, selecting environmentally sound – yet profitable – farm-management practices is inherently a multiple-objective decisionmaking problem. Policymakers must have access to accurate and sufficient information regarding the various environmental impacts of existing and proposed agricultural management systems. This report aims to provide MEMP staff with the tools to improve the accuracy of the information conveyed both to policymakers and to those scientists who may be interested in analyzing the information contained in current or future datasets.

Informed agricultural policy decisions must be based on sound technical advice. Technicians, scientists, and farmers need to attain a close level of cooperation to ensure successful culmination of organized experimental studies and data collection campaigns. Furthermore, technical personnel need to be familiar with the basic scientific concepts underlying experimental studies. Such familiarity is an invaluable asset to any environmental monitoring program, because it equips project personnel with the necessary skills to:

1. Monitor the quality of data,
2. Take scientifically-based actions,
3. Perform initial data analyses with potential uses of the data in mind,
4. Be able to work within interdisciplinary teams; and above all,
5. Communicate these concepts to farmers.

To aid readers in attaining familiarity with these basic scientific concepts, Section 2 provides a brief description of the hydrologic cycle, erosion and sedimentation processes, and the nutrient cycle from an agricultural perspective. Detailed technical discussions are avoided whenever possible without compromising the quality of the information provided.

2. Scientific Concepts

2.1. The Hydrologic Cycle

2.1.1. Description

As mentioned in Section 1.2, nonpoint source pollutants are suspended and dissolved materials carried by storm water over the land, into streams, and within the porous media of the soil. Clearly, water acts as the detaching agent of soil particles, dissolving agent of chemicals, and a transport agent of suspended and dissolved materials. It is imperative, therefore, to develop an understanding of the hydrologic cycle.

There are several possible conceptual models of the hydrologic cycle. These models are scale dependent and reflect the dominant hydrologic processes at that scale and for a specific situation. In this report, we focus on the agricultural aspects of the hydrologic cycle. Figure 2 is a schematic diagram of the components of the hydrologic cycle for agricultural lands.

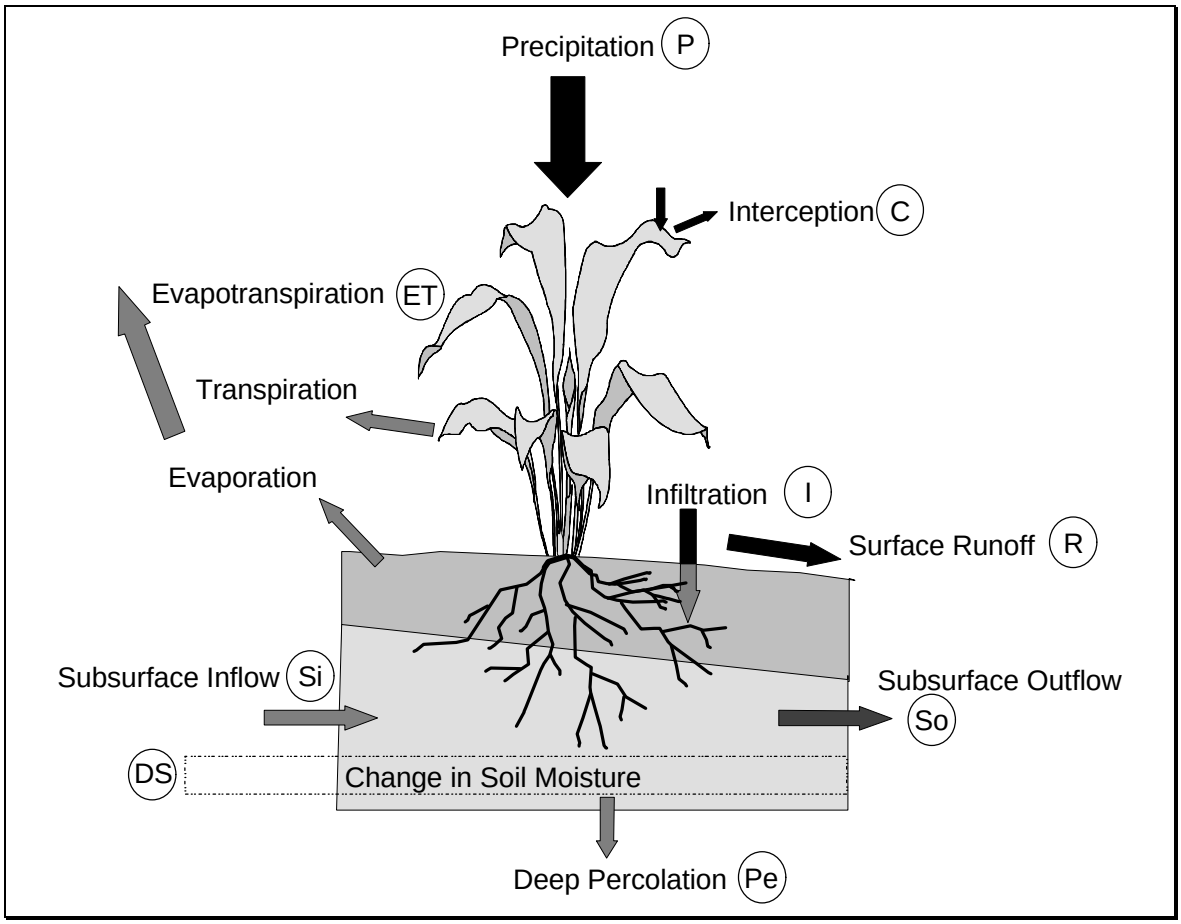


Figure 2. Simplified diagram of the main components of the hydrologic cycle as applied to a representative column of soil. Note that infiltration is an output from the surface component as well as an input to the soil component of the cycle.

Figure 2 provides guidance for constructing a version of the conservation of mass equation. Conservation of mass for any confined volume is based on Equation (1), which states that the change of storage (S) within the volume equals the difference between the inflow to the volume and the outflow from the volume.

$$\Delta S = \text{Inflow} - \text{Outflow} \qquad (1)$$

When the soil is the storage reservoir, water inputs to the profile comes from infiltration (*I*) which is the process by which storm water enter the profile, and lateral subsurface inflow (S_i). The output processes are deep percolation (P_e), which is the vertical flow of excess moisture below the root zone, lateral subsurface outflow (S_o), and evapotranspiration (ET), a combination of plant transpiration and surface evaporation. The continuity equation describing change of soil moisture (ΔSM) is written as:

$$\Delta SM = S_i + I - ET - P_e - S_o \qquad (2)$$

At the surface (solid arrows in Figure 2), the input is the storm rainfall (*P*). The outputs are infiltration, interception (the amount of rainfall intercepted by plants, *C*), and surface runoff (*R*). In this case, the continuity equation, assuming no surface storage, becomes:

$$R = P - \underbrace{(I + C)}_{\text{"abstract"}} \qquad (3)$$

The combined infiltration and interception term is called the "abstract." Note that infiltration represents a component connecting surface with subsurface processes.

In agricultural lands, interception can be assumed negligible. Substituting for infiltration from Equation 3 and assuming $C = 0$, Equation (2) can thus be rewritten as:

$$\Delta SM = S_i + P - R - ET - P_e - S_o \qquad (4)$$

Equation 4 is a simple continuity equation for a daily soil moisture balance; it assumes a single-layered soil profile.

For the agricultural hydrologic cycle, precipitation, infiltration, and runoff are the most important processes for NPSP loading. Precipitation causes soil detachment (discussed in Section 2.2.1). Runoff carries suspended and dissolved materials overland, to streams, and hence to water bodies. Infiltration on the other hand, carries dissolved nutrients from the surface to the soil to be utilized by plants. However, some of these nutrients find their way to below the root zone, arriving eventually at the groundwater aquifer through the process of deep percolation.

Infiltration is the major source of the abstract from a rainfall event. The amount of infiltration during a storm determines the amount of rainfall available for runoff. Infiltration is a function of several factors, including soil properties, initial soil moisture at the beginning of the storm, and the intensity of rainfall during the storm. Soil properties such as the saturated conductivity (the rate at which water flows through saturated soil), field capacity (the maximum amount of water that can be held in the soil against gravitational pull), and porosity (the ratio of the volume of pores within the soil to the total soil volume), affect the total infiltration by determining the rate of water movement into the soil. Modeling the infiltration process in details is a complicated process that requires detailed information about the soil and the intensity rainfall events. As was the case in the plot/pit studies in Malawi, in the absence of rainfall intensity data there are simpler models that relate the total amount of runoff to the total amount of rainfall under given soil and cover conditions. One of these models is the U.S. Soil Conservation Service Curve Number (SCS-CN) method.

2.1.2. The SCS-CN method

Originally, the SCS-CN method was developed for extreme runoff events, and is based on the concept of "initial abstraction." Basically, the relationship in Equation 5 expresses the total daily runoff volume as a function of the initial abstraction and the total infiltration (Hawkins, 1978):

$$Q = \frac{(P - I_a)^2}{(P + S - I_a)} \quad \text{for } P > I_a \qquad (5)$$

$$Q = 0 \quad \text{for } P \leq I_a$$

where

Q = total daily runoff volume,

P = total daily precipitation,

I_a = initial abstraction, and

S = maximum potential difference between rainfall and runoff at the beginning of the storm.

Data from several locations indicate that there is a relationship between I_a and S. This relationship is expressed as:

$$I_a = \beta S \qquad (6)$$

where β is a coefficient ranging between 0 and 1. Substituting (6) in (5):

$$Q = \frac{(P - \beta S)^2}{(P + S[1 - \beta])} \quad \text{for } P > I_a \qquad (7)$$

$$Q = 0 \quad \text{for } P \leq I_a$$

The variable S is a function of surface cover and soil type, while the parameter β is a function of antecedent moisture conditions, and indicates the amount of storage available in the soil. S is empirically related to a curve number coefficient (CN) ranging between 0 and 100 that can be identified from soil hydrologic conditions by Equation (8) for Imperial units (inches) and Equation (9) for metric units (mm) for both rainfall and runoff.

$$\text{CN} = \frac{1000}{10 + S} \qquad (8)$$

$$\text{CN} = \frac{25400}{254 + S} \qquad (9)$$

The relationships between CN and soil types are given in several handbooks and publications (e.g., U.S. Soil and Conservation Service, 1985). However, these predetermined CN values are normally used in conjunction with design problems, such as the construction of hydraulic structures (levees, pipes, drainage ditches, etc.). For agricultural applications, any of several CN values can be used for similar land management practices, according to the soil hydrologic group (i.e., the soil drainage capacity).
A value of β = 0.2 is used for most applications, which corresponds to a 50 percent probability that an event with rainfall P will produce runoff (Hawkins *et al.*, 1985). Other values for a 10 percent and a 90 percent probability are 0.085 and 0.456 respectively. For β = 0.2, Equation 7 becomes:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{for } P > I_a \qquad (10)$$

$$Q = 0 \quad \text{for } P \leq I_a$$

Figure 3 represents the SCS-CN relationship for different CN values. Note that runoff does not begin until precipitation exceeds a certain value for any of the curves. These values correspond to the condition $P > 0.2S$, where S is computed from the inverse of Equation 9, i.e.:

$$S = \frac{25400}{\mathrm{CN}} - 254 \qquad \textbf{(11)}$$

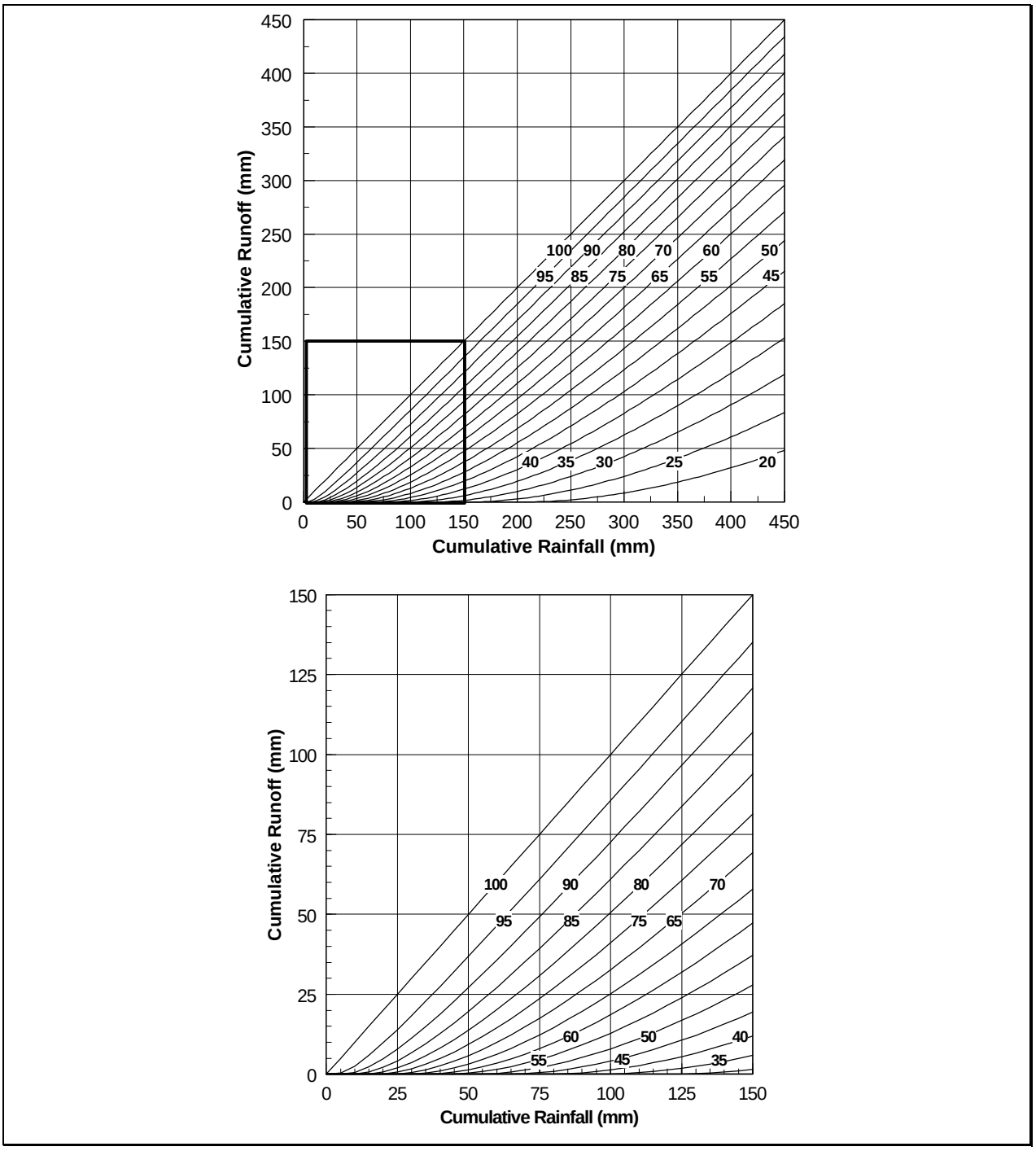


Figure 3. The SCS curve number relationship. The bottom chart represents the area outlined by the square in the top chart.

2.1.3. Curve Number Identification from Rainfall Runoff Records

2.1.3.1. CN determination for a single event

Equation (10) is the most commonly used form of the SCS rainfall runoff model. It can be solved for *S* directly using the quadratic formula, with Equation (9) then applied to evaluate the curve number. Alternatively, diagrams such as those presented in Appendix A can be used to identify the curve number directly. However, the first method is more appropriate when determining a curve number for a given catchment using several rainfall runoff events.

For a given rainfall runoff event, Equation (10) can be expanded as follows:

$$Q(P + 0.8S) = (P - 0.2S)^2 \qquad (12)$$

Further expansion of Equation (12) yields:

$$QP + 0.8QS = P^2 - 0.4PS - 0.04S^2 \qquad (13)$$

Collecting terms:

$$\underset{<a>}{0.04S^2} \underset{<b>}{-0.4(P+2Q)S} + \underset{<c>}{(P^2 - PQ)} = 0 \qquad (14)$$

Clearly, the above equation is a quadratic equation in *S*. Its solution can be found by

$$S = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad (15)$$

Substituting the values of a, b, and c from the quadratic equation results in two solutions. The solution satisfying the condition P > 0.2*S* corresponds to the negative sign of the square root, i.e.,

$$S = 5(P + 2Q - \sqrt{4Q^2 + 5PQ}) \qquad (16)$$

<u>Example:</u>

Consider the following event, which occurred in Chilindamaji catchment monitoring site near Nkhata Bay on the April 2, 1994. Total rainfall was 107.5 mm. Four runoff measurements were made at four different field pits (Section 3). Table 1 lists the measured runoff and the corresponding calculations. Runoff values in Table 1 differ from measured values because of a correction procedure, described in detail in Section ##.

Table 1. Sample CN Calculations from a Single Rainfall-Runoff Event

Data			Calculations			
Pit #	*P* (mm)	*Q* (mm)	$4Q^2+5PQ$	$P+2Q$	*S*	CN = (25400/(254+*S*))
1	107.5	15.8	9471.1	139.0	208.6	54.9
2	107.5	28.7	18744.0	165.0	140.3	64.4
3	107.5	33.7	22688.8	175.0	121.8	67.6
4	107.5	14.6	8680.5	136.6	217.4	53.9

It is important to recognize that a single event does not provide sufficient information about the rainfall-runoff relationship for a given catchment. For example, consider Figure 4, which illustrates the CN values for several rainfall events.

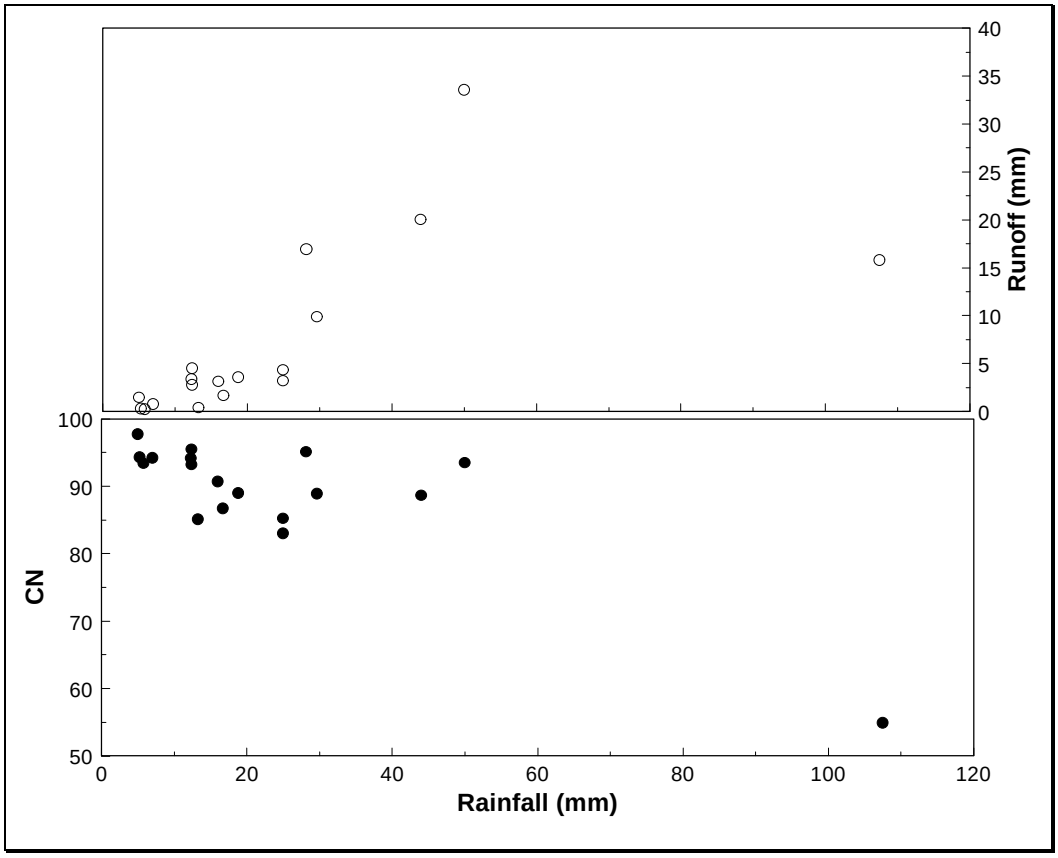


Figure 4. Example of the rainfall-runoff relationship for Pit #1 in Chilindamaji, near Nkhata Bay, Malawi. Note that the rainfall-runoff curve does not correspond with a unique CN.

2.1.3.2. Determining catchment curve number from multiple events

2.1.3.2.1. The average curve number approach

There are several methods that can be used to determine the CN of a given catchment using multiple rainfall-runoff events. The first method is based on estimating the mean value of the CNs from all events, as follows:

Step 1 Remove all non-runoff producing events from the sample. These events do not have the information that allows identification of CNs.

Step 2 For the remaining runoff-producing events, compute the CN associated with each event using Equation (16) to calculate *S* and Equation (9) to estimate the CN.

Step 3 Compute the average value of the sample using the relationship in Equation (17).

$$CN_e = \frac{\sum_{i=1}^{n} CN_i}{n} \qquad (17)$$

where

CN_e = the average (estimated) curve number,

CN_i = the computed curve number for the *i*th runoff producing event,

n = the number of runoff producing events.

Step 4 Compute S_e (estimated soil water storage) associated with the average CN by substituting CN_e from Equation (17) for CN in Equation (11).

Step 5. Compute the estimated runoff Q_{e_i} for each rainfall event by substituting P_i for P and S_e for S in Equation (10). Be careful to check for the condition $P_i > 0.2S_e$. Some of the events will not satisfy the condition; in these cases, $Q_{e_i} = 0.00$.

Step 6. Plot the observed Q_i against the estimate Q_{e_i}. Notice if there is a spread about the 1:1 line (the line can be drawn by plotting Q_i against itself on both axes). We also recommend using some measure of errors in the estimation, such as R^2 and/or the error sum of squares.

Example: Table 2 illustrates these computations for the dataset from Pit #1.

Table 2. An Example Average CN Computation

P_i	Q_i	S_i	CN_i	Q_e	Square Error
25.0	4.3	44.1	85.2	11.3	48.0
25.0	3.2	52.2	83.0	11.3	65.4
12.4	4.5	12.2	95.4	3.3	1.4
50.0	33.6	17.8	93.4	31.7	3.6
12.3	3.3	15.8	94.1	3.3	0.0
16.7	1.6	39.1	86.6	5.7	16.6
13.3	0.4	44.6	85.1	3.8	11.5
12.4	2.8	18.7	93.2	3.3	0.3
16.0	3.1	26.3	90.6	5.3	4.7
7.0	0.8	15.8	94.1	1.0	0.1
5.0	1.5	6.1	97.7	0.0	2.1
18.8	3.5	31.6	88.9	7.0	12.1
28.2	16.9	13.1	95.1	13.6	10.6
5.8	0.2	18.0	93.4	0.0	0.1
5.3	0.3	15.6	94.2	0.0	0.1
107.5	15.8	208.6	54.9	85.2*	4815.8*
29.7	9.9	31.9	88.9	14.8	24.2
44.0	20.0	32.7	88.6	26.5	41.5
		$S_e = 31.3$ $0.2S_e = 6.3$	$CN_e = 89.0$		error sum of squares = 5058.2

* These values seem to be very high, and correspond with the largest rainfall event, 107 mm. Such high values complicate the computation of R^2.

The main problems with using the average value of all computed event CNs are discussed by Hawkins (1978), Hawkins *et al*. (1985), Hjelmfelt (1980), and Ponce and Hawkins (1996). Clearly, the method tends to weigh all events equally. Since runoff-producing low-rainfall events are associated with higher CNs, the method tends to overestimate the catchment CN. Higher rainfall events that also produce runoff are then modeled as catastrophic runoff events, as occurred for the 107 mm event in Table 2 above.

2.1.3.2.2. The Hawkins-Hejlmfelt-Zevenbergen (HHZ) approach

Hawkins *et al*. (1985) proposed calculating catchment CNs from historical rainfall-runoff records, a method based on probability assessments and first proposed by Hjelmfelt (1980). The HHZ approach identifies a subset of events that contains the necessary information about the catchment response. This subset corresponds to the condition $P/S_e > 0.456$, which indicates a 90% probability of runoff occurrence. Such a set is primarily a set of the largest rainfall events (but not necessarily the highest runoff events). The procedure for obtaining a CN using HHZ is as follows:

Step 1 Remove all non-runoff producing events from the sample. These events do not have the information that allow CN identification.

Step 2 For the remaining runoff-producing events, sort all events in descending order of rainfall.

Step 3 Starting from the largest rainfall event, compute the storage parameter S_i from Equation (16).

Step 4 Check for the cutoff value $P_i/S_i > 0.456$.

Step 5 If $P_i/S_i > 0.456$, add the next biggest storm to the calculation. Compute S_i for this storm and compute S_e, the average value corresponding to the storms that have entered the calculation. Go back to Step 4.

Step 6 Include all events where $P_i/S_e > 0.456$. This means that if P/S_e becomes < 0.456, continue the procedure until no more cases of P/S_e are > 0.456. Once this subset of events is identified, from Equation (9) compute the CN from S_e corresponding to the last incidence of $P/S_e > 0.456$.

Step 7 Compute the estimated runoff Q_{e_i} for each rainfall event by substituting P_i for P and S_e for S in Equation (10). Be careful to check for the condition $P_i > 0.2S_e$. Some of the events will not satisfy the condition. In these cases, $Q_e = 0.00$.

Step 8 Plot the observed Q_i against the estimate Q_{e_i}. Notice if there is a spread about the 1:1 line (the line can be drawn by plotting the Q_i against itself on both axes). We also recommend using some measure of errors in the estimation, such as R^2 and/or the error sum of squares.

Note that not all datasets provide a good sample for this method. Some datasets will not contain any storms with $P_i/S_i > 0.456$, and HHZ must not be used. Such "empty" datasets imply that the catchment has a low CN that cannot be identified from the available record (Hawkins *et al*., 1985). A longer record may be helpful, but there is no guarantee of determining a CN value. For such cases, the authors suggest trying to develop a catchment's rainfall-runoff relationship from regression analysis, or using the frequency-matching method (see Section 2.1.3.2.3). Table 3 illustrates the computations associated with HHZ for the same dataset as we use in Table 2. Note that only four events actually contributed to the computation of the catchment CN ($CN_e = 80.7$).

Table 3. Sample Calculation of Catchment CN Using the HHZ Approach

P	Q	S_i	S_e	P/S_e	CNe	Notes	Q_e (CN=80.7)
107.5	15.8	208.6	208.6	0.5153	54.9	Included in CN calculation	58.2
50.0	33.6	17.8	113.2	0.4417	69.2		14.5
44.0	20.0	32.7	86.4	0.5095	①74.6		10.9
29.7	9.9	31.9	72.7	0.4083	77.7		3.9
28.2	16.9	13.1	60.8	0.4637	②80.7	Last $P/S_e > 0.456$	3.3
25.0	3.2	52.2	59.4	0.4211	81.1	Not included in the calculation	2.2
25.0	4.3	44.1	57.2	0.4371	81.6		2.2
18.8	3.5	31.6	54.0	0.3482	82.5		0.7
16.7	1.6	39.1	52.3	0.3191	82.9		0.3
16.0	3.1	26.3	49.7	0.3217	83.6		0.2
13.3	0.4	44.6	49.3	0.2699	83.8		0.0
12.4	4.5	12.2	46.2	0.2685	84.6		0.0
12.4	2.8	18.7	44.1	0.2814	85.2		0.0
12.3	3.3	15.8	42.0	0.2925	85.8		0.0
7.0	0.8	15.8	40.3	0.1737	86.3		0.0
5.8	0.2	18.0	38.9	0.1491	86.7		0.0
5.3	0.3	15.6	37.5	0.1412	87.1		0.0
5.0	1.5	6.1	35.8	0.1001	87.7		0.0
						Error Sum of Squares =	2530.4

Notes: Notice that the largest event produced runoff corresponding to a very low CN. Observe that the procedure did not stop at ①, following which P/S_e was < 0.456 for one event; instead, the procedure requires finding the **last** $P/S_e > 0.456$.

2.1.3.2.3. The frequency-matching technique.

A third possible method for identifying catchment curve number from rainfall-runoff records is the frequency-matching technique. The technique requires matching the largest rainfall events with the largest runoff events of every year. For this technique to work properly, many years of data are needed. Because this report deals with a single year of record, utilization of this method is considered beyond its scope.

2.1.4. Estimating CNs from Handbooks for Ungaged Catchments

Handbook estimates of CN values can be made for ungaged catchments. These estimates are obtained by relating the CN to the soil–plant-cover complex for given antecedent moisture conditions. Four soil hydrologic groups are defined (see Table 4 below). Any soil can be classified under one of these groups based on its permeability measure. If a particle-size distribution of the soil is available, a textural class can be identified according to the USDA textural classification system based on the percent occurrence of sand, silt and clay.

Table 4. Soil Hydrologic Groups Classified According to Saturated Hydraulic Conductivity

Hydrologic Group	Saturated Hydraulic Conductivity (cm/hr)	
	Lower Bound	Upper Bound
A	0.76	1.27
B	0.38	0.76
C	0.13	0.38
D	0.01	0.13

Antecedent moisture conditions (AMC) reflect the impact of previous rainfall events on the soil's moisture-holding capacity. The more of this capacity that is filled by previous events, the less is available to store the current storm's infiltration. Thus, higher values of runoff from the storm can be expected. Table 5 depicts the relationship between AMC and the amount of rainfall during the five preceding days. Note that during a single growing season, more rainfall is required to produce a higher AMC. Table 6 shows CN values based on AMC, hydrologic soil classification and conditions, and the land cover/land management system.

Table 5. Identification of Antecedent Moisture Conditions

AMC Group	Five-Day Rainfall (mm)			
	Dormant Season		Growing Season	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
I		12.70		35.0
II	12.70	28.00	35.0	53.0
III	28.00		53.0	

Table 6. Handbook CN Identification

Land Cover and Land Management System	Hydrologic Conditions	Hydrologic Group											
		A			B			C			D		
		Antecedent moisture conditions											
		I	II	III	I	II	III	I	II	III	I	II	III
Fallow													
SR		70	77	81	82	86	88	89	91	92	93	94	95
SR+CT	poor	68	75	80	81	84	86	87	89	90	91	92	93
SR+CT	good	67	74	79	80	83	89	86	87	88	89	90	91
Row Crops													
SR	poor	65	72	77	78	81	85	86	87	88	90	91	92
SR	good	60	67	73	74	78	82	83	85	87	88	89	90
SR+CT	poor	66	71	75	76	79	83	84	86	87	88	89	90
SR+CT	good	57	64	70	71	75	79	80	82	83	84	85	86
CNT	poor	64	70	75	76	79	81	82	84	86	87	88	89
CNT	good	59	65	70	71	75	79	80	82	84	85	86	87
CNT+CT	poor	63	69	74	75	78	80	81	83	85	86	87	88
CNT+CT	good	58	64	69	70	74	77	78	80	82	83	84	85
CNT+TER	poor	60	66	70	71	74	77	78	80	81	81	82	83
CNT+TER	good	56	62	66	67	71	74	75	78	79	80	81	82
CNT+TER+CT	poor	59	65	69	70	73	76	77	79	80	80	81	82
CNT+TER+CT	good	55	61	66	67	70	73	74	76	77	78	79	80
Small Grain													
SR	poor	60	65	70	71	76	80	81	84	86	87	88	89
SR	good	57	63	69	70	75	79	80	83	85	86	87	88
SR+CT	poor	58	64	69	70	74	78	79	82	84	85	86	87
SR+CT	good	53	60	67	68	72	76	77	80	82	83	84	85
CNT	poor	57	63	68	69	74	78	79	82	83	84	85	86
CNT	good	55	61	67	68	73	77	78	81	82	83	84	85
CNT+CT	poor	56	62	67	68	73	77	78	81	82	83	84	85
CNT+CT	good	53	60	66	67	72	75	76	79	80	81	82	83
CNT+TER	poor	56	61	66	67	72	75	76	79	80	81	82	83
CNT+TER	good	54	59	64	65	70	74	75	78	79	80	81	82
CNT+TER+CT	poor	55	60	65	66	71	74	75	78	79	80	81	82
CNT+TER+CT	good	53	58	63	64	69	72	73	76	77	78	79	80

continued

Table 6 (continued)

Land Cover and Land Management System	Hydrologic Conditions	Hydrologic Group											
		A			B			C			D		
		Antecedent moisture conditions											
		I	II	III	I	II	III	I	II	III	I	II	III
Close-seeded legumes, or rotation meadow													
SR	poor	61	66	71	72	77	81	82	85	87	88	89	90
SR	good	51	58	65	66	72	76	77	81	83	84	85	86
CNT	poor	59	64	69	70	75	78	79	83	84	85	85	86
CNT	good	48	55	62	63	69	73	74	78	80	81	83	85
CNT+TER	poor	58	63	68	69	73	76	77	80	81	82	83	84
CNT+TER	good	43	51	59	60	67	71	72	76	78	79	80	81
Pasture/Range													
Non-CNT	poor	60	68	73	74	79	82	83	86	87	88	89	90
Non-CNT	fair	35	49	60	61	69	74	75	79	81	82	84	86
Non-CNT	good	25	39	51	52	61	67	68	74	77	78	80	83
CNT	poor	32	47	58	59	67	74	75	81	84	85	88	90
CNT	fair	5	25	4	46	59	67	68	75	78	79	83	87
CNT	good	1		6	24	35	55	56	70	74	75	79	83
Meadow													
———	good	51	59	66	67	74	78	79	82	84	85	86	87
Woods													
———	poor	33	45	55	56	66	71	72	77	80	81	83	85
———	fair	22	36	48	49	60	66	67	73	76	77	79	81
———	good	8	25	4	42	55	62	63	70	73	74	77	80
Farmsteads													
———	———	42	59	67	68	74	78	79	82	84	85	86	87
Roads													
Dirt	———	66	72	77	78	82	84	85	87	88	88	89	90
Hard surfaces	———	68	74	79	80	84	87	88	90	91	91	92	93

SR = Straight Row; CT = Conservation Tillage; CNT = Contoured; TER = Terraced

Based on the probabilistic interpretation of the SCS-CN method mentioned above, AMC groups I, II, and III correspond, respectively, with a 10%, 50%, and 90% probability of runoff being produced for a given storm.

CN estimates from handbooks can be modified to reflect improved land management activities. One of these activities is the no-till management system. Generally, these modifications are crop-dependent and related to the amount of post-harvest residue allowed to remain on the field surface.

2.2 Water Erosion Processes

2.2.1. General Description

Water erosion dislodges soil particles from the soil aggregates within the surface soil layer due to the impact of rainfall drops (Figure 5) or due to the dynamic forces of overland flow. Erosion can also occur along stream and river banks. In this report, we discuss only rainfall-drop impact and overland flow effects on agricultural fields.

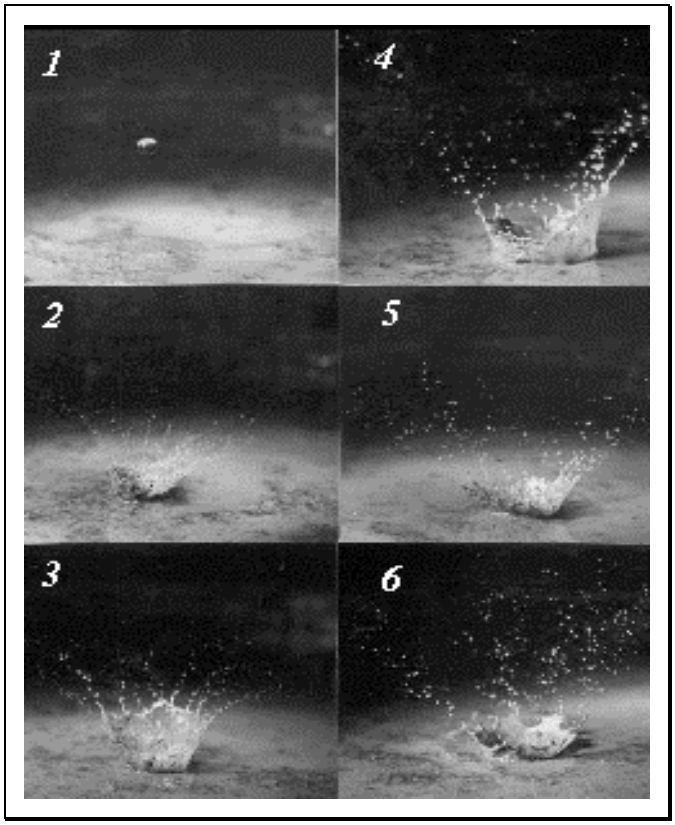


Figure 5. A photographic sequence illustrating the impact of raindrop splash. Note the presence of soil particles (frame 6), which have been kinetically detached from the soil surface by the splash.

Water erosion has three main forms.

- Sheet erosion: the uniform removal of soil particles from the surface without causing channelization.
- Rill erosion: the removal of soil through the cutting of a large number of small rivulets and tiny channels. These channels are not permanent and change location with each storm event. However, under certain conditions, some rills may develop into larger channels causing the third form of water erosion which is gully erosion.
- Gully erosion: the removal of soil through cutting relatively large channels or gullies by the force of concentrated flow.

Both water erosion and sediment transport are complex processes involving interactions among climate, soil properties, topography, surface cover, and human activities (Renard, 1992). Of these, climate represents the active force of erosion, while soil, topography, and surface cover represent passive factors. Human activities cause changes in the passive factors, thereby altering a catchment's response to climate. An example of the substantial connection among the factors is that of rainfall intensities high enough to cause splash erosion. The breakup of surface soil aggregates, together with the dislodgment and dispersion

of soil particles, may seal the surface soil and result in decreased infiltration rates and increased runoff, which augments overland flow. Soil properties such as granulation, texture, structure, water holding capacity, and permeability are factors that determine the runoff amount, as well as the soil erodibility and the ability of overland flow to transport detached sediments.

2.2.2. The Universal Soil Loss Equation (USLE)

One of the most widely used soil erosion models is Wischmeier and Smith's (1978) USLE. In its original version, the model takes the form:

$$A = R \times K \times L \times S \times C \times P \qquad (17)$$

where

A = the sediment yield for the period in question,

R = the rainfall-runoff erosivity index,

K = the soil-erodibility factor,

L = the length-of-slope factor,

S = the degree-of-slope factor,

C = the crop-management factor,

P = the conservation-practice factor.

R characterizes the level of attacking (active) forces while the remaining terms characterize the level of resisting (passive) forces. These factors have been determined from experimental studies that compared erosion rates from different erosion-monitoring plots.

Central to the USLE is the concept of a "unit plot." A universal unit plot is utilized to determine the soil-erodibility factor, K (Figure 6). Additional plots are used to determine other parameters. Except for the factor being assessed, such plots must represent the field for which parameters are being determined, and must also be identical to its counterpart in the universal plot. For example, determining the slope-steepness factor for a field that has a 5% slope requires two experimental plots. The first plot should have the actual field slope of 5%, while the second plot should be identical in length, tillage, soil, and land cover to the first plot but with a 9% slope (the USLE standard). Similarly, in order to estimate the slope-length factor L for a slope of 5% and a length of 100 m, two plots identical in soil, cover, and practice must be used. Both plots have the 5% slope. The first plot (the field plot) must be 100 m long, while the unit plot must be 22.13 meters long (the USLE standard).

Determining the factors K, C, and P is experimentally intensive. It requires constant monitoring and in some cases rainfall simulation experiments. The standard approach of obtaining experimental values of the USLE factors involves fixing five of the six factors by means of standardized plots and monitoring rainfall, runoff, and erosion. Once the data are available, the USLE equation can be solved for the unknown factor. However, plot studies cannot measure sediment delivery from large watersheds, where A is determined primarily by the capacity of watercourses to transport sediment.

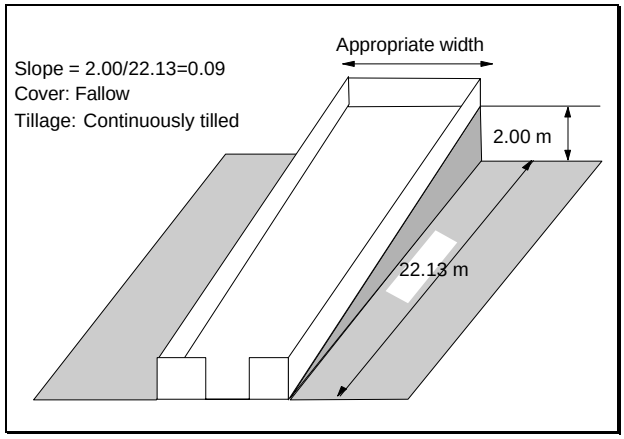


Figure 6. Schematic diagram of the USLE standard plot used to determine K, the soil-erodibility factor.

2.2.3. Computation of USLE Factors

The original USLE handbook states:

> "Numerical values for each of the six factors were derived from analysis of the assembled research data and from U.S. National Weather Service precipitation records. For most conditions in the U.S. the approximate values of these factors for any particular site may be obtained from charts and tables in this handbook. *Localities or countries where rainfall characteristics, soil, topographic features, or farm practices are substantially beyond the range of present U.S. data will find these charts and tables incomplete and perhaps inaccurate for their conditions* [emphasis ours]. However, they will provide guidelines that can reduce the amount of local research needed to develop comparable charts and tables for their conditions."

This statement provides the guidelines for proper interpretation of handbook values. Subsequent research has modified the USLE to enable its use for single-storm erosion-loss predictions. Several of these modifications derive approximate values of USLE factors, and are discussed below. Some of these methods may not be applicable at the present time to MEMP watersheds because required data are lacking. However, researchers at MEMP will be able to determine, based on the information below, the type of data and the extent of data collection required to estimate soil loss factors for prevailing conditions in Malawi. To assist in this task, we provide hypothetical and numerical examples.

2.2.3.1. *R*, the rainfall-runoff erosivity index

R is a statistical measure calculated from a summation of rainfall energy in every storm over a fixed period of time (correlated with raindrop size) multiplied by its maximum 30-minute intensity. Empirically, *R* was found to have the highest correlation with soil erosion from experimental plots. For each intensity period, a rainfall energy e_m per unit intensity is computed (Foster, 1981) from:

$$\begin{aligned} e_m &= 0.119 + 0.0873\log(i_m) && \text{for } i_m \le 76 \text{ mm/h} \\ e_m &= 0.283 && \text{for } i_m > 76 \text{ mm/h} \end{aligned} \qquad (18)$$

where

e_m = the kinetic energy of the *m*th intensity period for a unit rainfall (MJoules/ha•mm),

i_m = the rainfall intensity period energy (mm/h).

Once the unit energy for each storm intensity period is obtained, the total energy for the intensity period is calculated by multiplying e_m by the total amount of rainfall that occurred during the interval. That is,

$$E_m = e_m p_m \qquad (19)$$

The values obtained from Equation (19) are summed and then multiplied by the maximum 30-minute intensity, I_{30}, giving EI, the total kinetic energy of the storm.

$$\mathrm{EI} = (\sum_{m=1}^{M} E_m) I_{30} \qquad (20)$$

The procedure for computing R is best demonstrated through a step-by-step example. Consider the hypothetical rainfall chart (Figures 7a and 7b). Figure 7a represents the cumulative precipitation for a storm as a function of time, and is termed a "break-point diagram." Figure 7b is a storm hyetograph, and indicates the rainfall intensity for periods that can be considered to have a constant intensity. The hyetograph is generated using Equation (21).

$$i_m = \frac{p_m}{\Delta t_m} \times 60 = \frac{Pe_m - Ps_m}{te_m - ts_m} \times 60 \qquad (21)$$

where

i_m = the intensity for the *m*th period (mm/h),

Pe_m = the cumulative rainfall at the end of the *m*th period (mm),

Ps_m = the cumulative rainfall at the start of the *m*th period (mm),

te_m = the time at the end of the *m*th period (min),

ts_m = the time at the start of *m*th period (min), and

60 = the conversion factor mm/min to mm/h.

The 30-minute intensities are estimated by dividing the storm into 30-minute intervals and interpolating the cumulative precipitation at the end of every interval. The procedure is repeated for each new interval and its associated cumulative rainfall in order to select I_{30}. Note that the last interval may be less than 30 minutes, as is the case in the following example, where it is 10 minutes. The plots corresponding to these procedures are Figures 7c and 7d. Table 8 shows the calculation of the storm's energies.

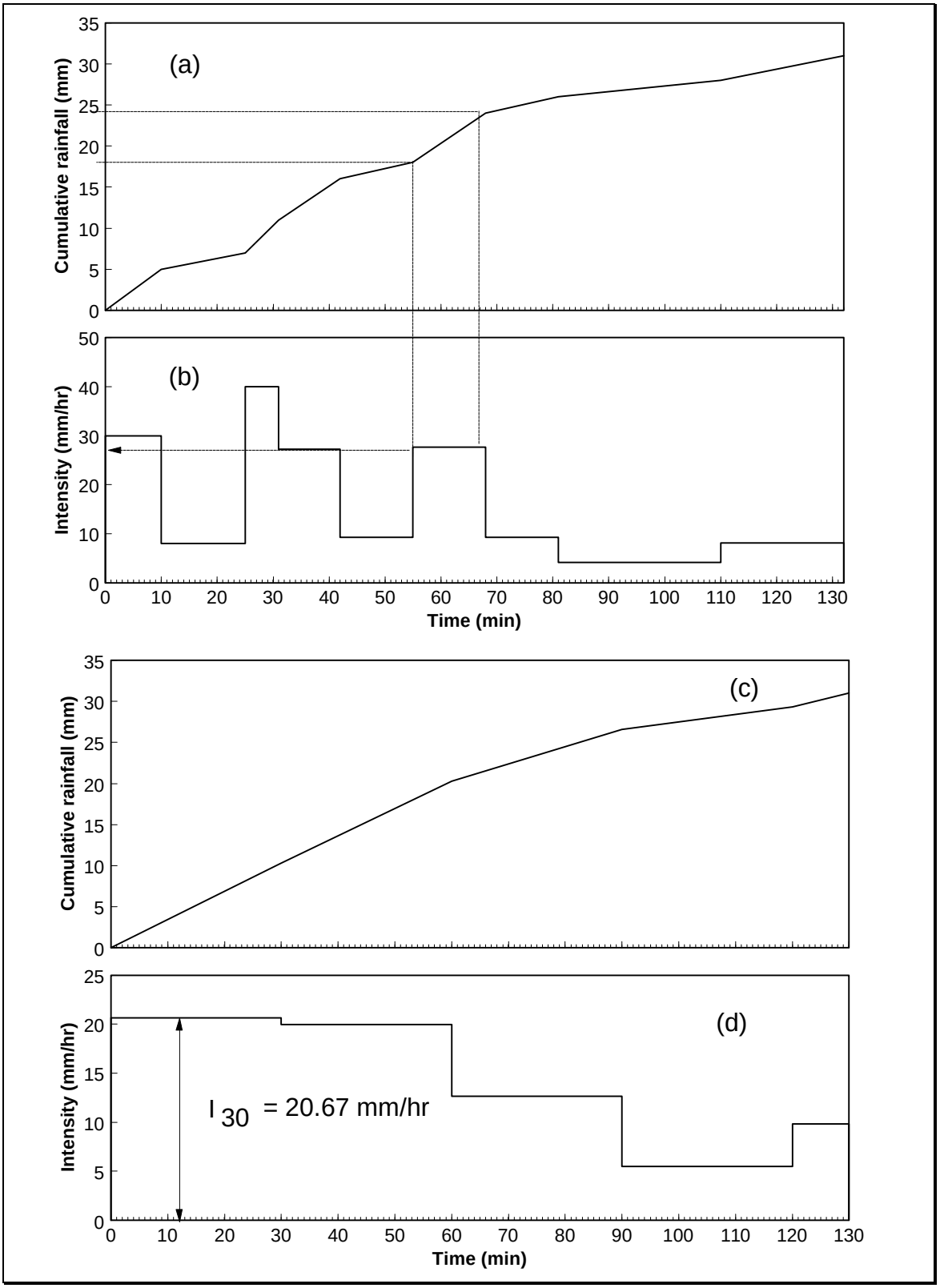


Figure 7. Break-point and hyetograph plots of a hypothetical storm for use in computing EI. Note the smoothing effect caused by the use of 30-minute intervals in (c).

Table 8. Steps in the Calculation of Total Storm Energy, EI.

m	ts_m (min)	te_m (min)	Ps_m (mm)	Pe_m (mm)	p_m (mm)	i_m (mm/h)	e_m (MJ/ha•mm)	E_m (MJ/ha)
1	0.0	10.0	0.0	5.0	5.0	30.00	0.25	1.24
2	10.0	25.0	5.0	7.0	2.0	8.00	0.20	0.40
3	25.0	31.0	7.0	11.0	4.0	40.00	0.26	1.04
5	31.0	42.0	11.0	16.0	5.0	27.27	0.24	1.22
6	42.0	55.0	16.0	18.0	2.0	9.23	0.20	0.41
7	55.0	68.0	18.0	24.0	6.0	27.69	0.24	1.47
8	68.0	81.0	24.0	26.0	2.0	9.23	0.20	0.41
9	81.0	110.0	26.0	28.0	2.0	4.14	0.17	0.35
10	110.0	132.0	28.0	31.0	3.0	8.18	0.20	0.60
								ΣEm = 7.12
								EI (MJ•mm/ha•h) = 147.11

Notes: i_m from Eqn. (21); e_m from Eqn. (18); E_m from Eqn. (19); and EI from Eqn. (20).

2.2.3.2. *K*, the soil-erodibility factor

This factor quantifies the cohesive character of a soil type and its resistance to dislodgment and transport due to raindrop impact and overland flow shear forces, both of which are particle size and density dependent. Erodibility of soil is a function of its structure, water retention properties, hydraulic conductivity, and prior erosion and sediment transport history. *K* can generally be determined based on known soil properties (Wischmeier and Smith, 1978). When detailed soil data are unavailable, estimates of *K* can be made using average particle size-distribution data from the textural classification of Table 9. When detailed information about soil structure and permeability class is available, *K* is computed using Equation (22). Note that the equation is invalid where the soil silt fraction exceeds 70 percent.

$$K = \frac{1}{7.95} \bullet \left(\underbrace{\frac{2.1\times10^{-4}\,M}{100}(12-a)}_{a} + \underbrace{\frac{3.25(b-2)}{100}}_{b} + \underbrace{\frac{2.5(c-3)}{100}}_{c} \right) \qquad (22)$$

where

$\frac{1}{7.95}$ = the conversion factor to metric units (t.ha.h/(ha.MJ.mm))

a = percent organic matter,

b = soil structure code:

- b = 1 for very fine granular soils,
- b = 2 for fine granular soils,
- b = 3 for medium or coarse granular soils, and
- b = 4 for blocky, platy, or massive soils.

c = soil profile permeability class:

- c = 1 for soils with rapid drainage,
- c = 2 for soils with moderate to rapid drainage,
- c = 3 for soils with moderate drainage,
- c = 4 for soils with slow to moderate drainage,
- c = 5 for soils with slow drainage, and
- c = 6 for soils with very slow drainage.

SF = the soil structure factor,
TF = the soil texture factor,
PF = the soil permeability factor.
M = the soil texture parameter: $M = (\text{silt} + \text{vfs})(100 \times \text{clay})$ (23)
where
silt = percent silt,
vfs = percent very fine sand,
clay = percent clay.

Table 9 shows the calculation of PF, TF, and SF for average USDA soil texture classifications, and assumes a value of vfs = (0.5×sand).

Table 9. *K* Factors Computed for Average Soil Properties for USDA Soil Texture Classes

Soil texture class	Clay %	Silt %	Sand %	TF	SF	PF
Coarse sand	5.0	5.0	90.0	0.0083	0.0325	-0.0500
Sand	5.0	5.0	90.0	0.0148	0.0325	-0.0500
Fine sand	5.0	5.0	90.0	0.0217	0.0000	-0.0500
Very fine sand	5.0	5.0	90.0	0.0440	-0.0325	-0.0500
Loamy coarse sand	8.0	8.0	84.0	0.0098	0.0325	-0.0250
Loamy sand	8.0	8.0	84.0	0.0162	0.0325	-0.0250
Loamy fine sand	8.0	8.0	84.0	0.0230	0.0000	-0.0250
Loamy very fine sand	8.0	8.0	84.0	0.0373	-0.0325	-0.0250
Coarse sandy loam	15.0	25.0	60.0	0.0191	0.0325	0.0000
Sandy loam	15.0	25.0	60.0	0.0255	0.0325	0.0000
Fine sandy loam	15.0	25.0	60.0	0.0321	0.0000	0.0000
Very fine sandy loam	15.0	25.0	60.0	0.0388	-0.0325	0.0000
Loam	20.0	35.0	45.0	0.0362	0.0325	0.0250
Silt loam	20.0	60.0	20.0	0.0426	0.0650	0.0250
Silt	10.0	85.0	5.0	0.0585	0.0650	0.0250
Sandy clay loam	25.0	20.0	55.0	0.0278	0.0650	0.0500
Clay loam	35.0	30.0	35.0	0.0236	0.0650	0.0500
Silty clay loam	35.0	50.0	15.0	0.0261	0.0650	0.0500
Sandy clay	40.0	10.0	50.0	0.0171	0.0650	0.0750
Silty clay	45.0	45.0	10.0	0.0187	0.0650	0.0750
Clay	50.0	30.0	20.0	0.0129	0.0650	0.0750

Note: The calculations assume a value of vfs = (0.5×sand). Source: Knisel, 1993.

Table 10 lists the permeability class *c* and hydrologic group of the 11 major USDA soil texture classes; it determines the PF with a higher degree of accuracy whenever the actual particle size distribution is available from field measurements (Figure 7). Notice that silt is absent from the table because of the inapplicabiliy of Equation (22) under conditions where the soil silt fraction exceeds 70 percent. However, Renard (1992) suggests that silt should be included under permeability class 3. Table 10 also includes ranges of saturated hydraulic conductivity, the primary indicator of a soil's drainage capability.

Table 10. Saturated Hydraulic Conductivity, Permeability Class, and Hydrologic Group of Major USDA Soil Texture Classes

Soil Texture Class	Saturated Hydraulic Conductivity		Permeability Class	Hydrologic Soil Group
	Lower Bound	Upper Bound		
Silt Clay Clay		1.0	6	D
Silt Clay Loam Sandy Clay	1.0	2.0	5	C-D
Sandy Clay Loam Clay Loam	2.0	5.0	4	C
Loam Silt Loam	5.0	20.0	3	B
Loamy Sand Sandy Loam	20.0	60.0	2	A
Sand	60.0		1	A+

Source: Renard, 1992.

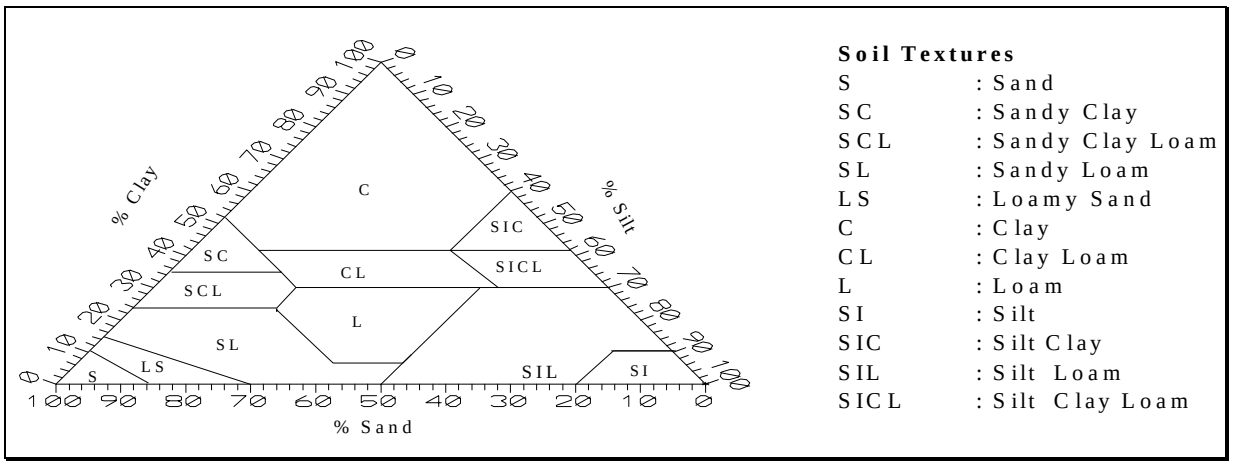


Figure 7. The USDA soil texture triangle. Use the triangle in conjunction with Table 10.

2.2.3.3. *LS*, the topographic factor

For convenience, the slope length factor *L* and slope steepness factor *S* are frequently conjoined into a single term because the effect of steeper slopes and longer slopes is similar. Steeper slopes produce higher overland flow velocities. Longer slopes allow for more accumulation of runoff from larger areas, also resulting in higher flow velocities. Both, therefore, nonlinearly increase erosion potential. For uniform slopes < 9% and longer than 5 m, the topographic factor is given by Equation (24), from which the nomogram of Figure 8 is constructed (Wischmeier and Smith, 1978; McCool *et al*., 1989a, 1989b).

$$LS = \left(\frac{\lambda}{22}\right)^m (65.41[\sin\theta]^2 + 4.56\sin\theta + 0.065) \qquad \textbf{(24)}$$

where

λ = the slope length (m),

θ = the slope angle, and

m = the slope steepness parameter:

m = 0.5 [slope > 5%]

m = 0.4 [3.5% < slope < 4.5%]

m = 0.3 [1% < slope < 3%], and

m = 0.2 [slope < 1%].

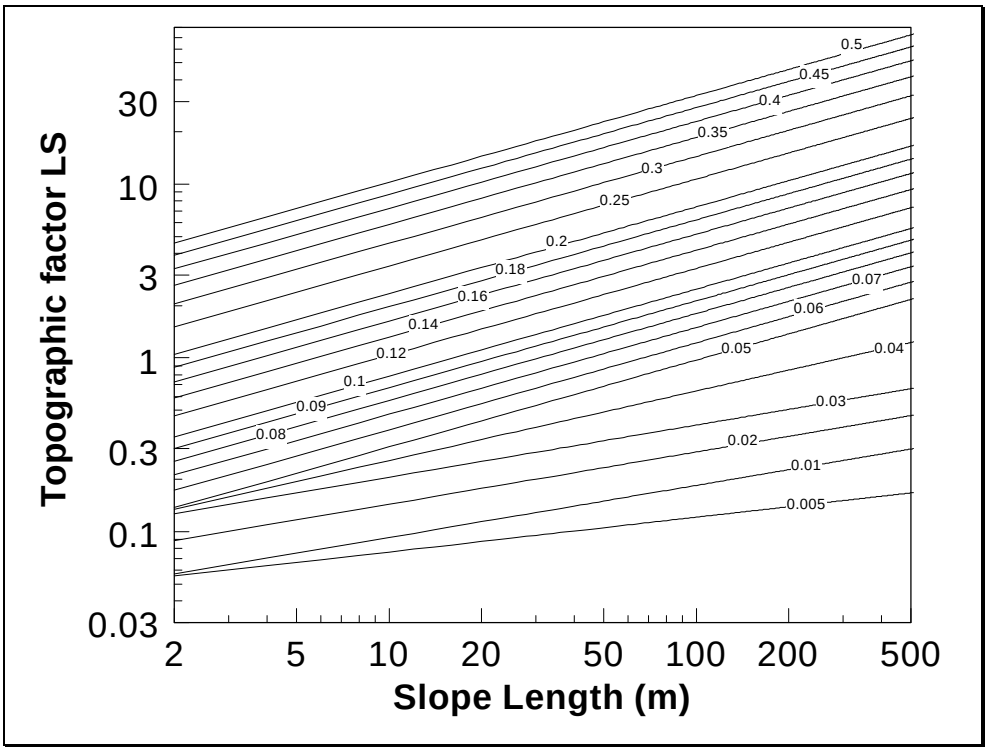


Figure 8. The topographic factor *LS* for different slopes and slope lengths. Enter the nomogram from the *x*-axis, find the line corresponding to the field slope, and read off the LS factor from the *y*-axis. Numbers on the curves are slopes of the overland flow profile (difference in elevation per unit length), in radians.

2.2.3.4. *C*, the crop-management factor:

C is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. The most computationally complex of the USLE factors, *C* incorporates tillage management, crop type, rotation history, and yield, and seasonal EI-index distribution. Figure 9 illustrates the impacts of surface cover on soil detachment, dislodgment, and sediment transport.

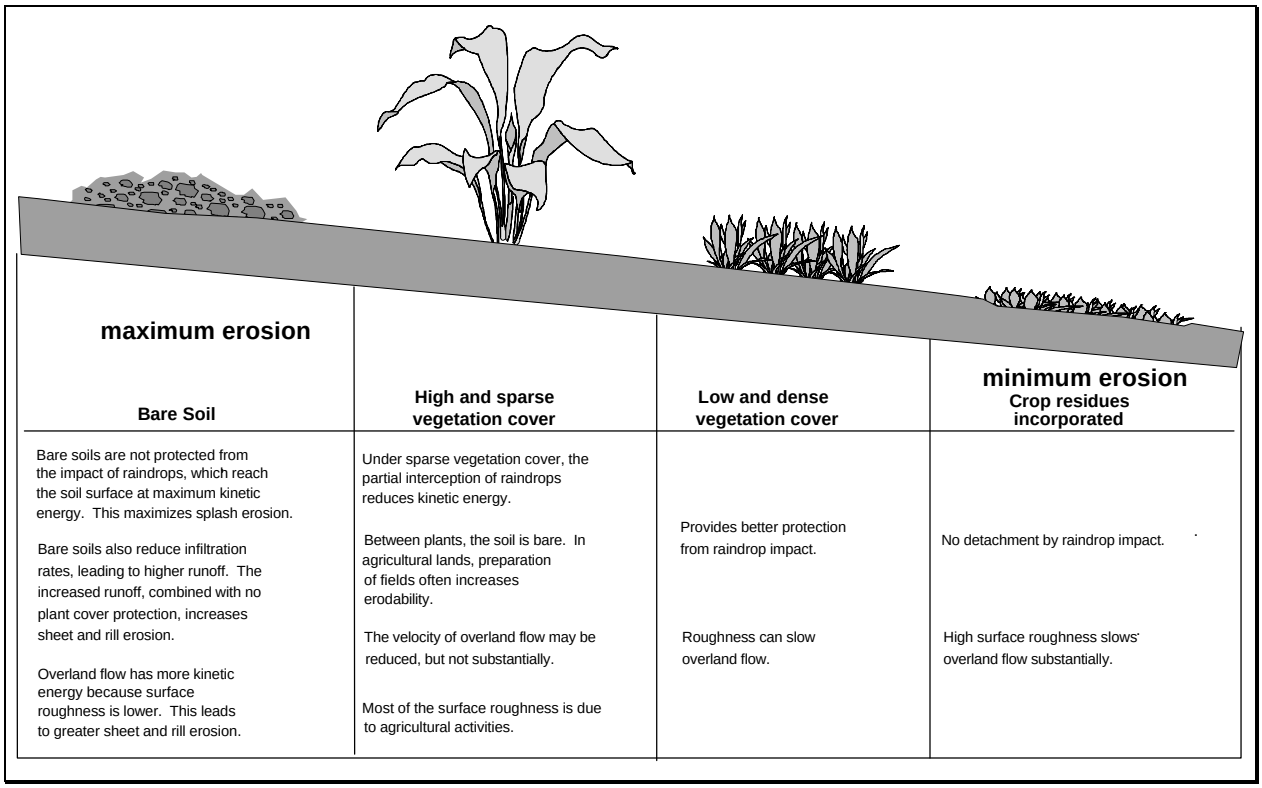


Figure 9. Schematic representation of the effect of surface cover on soil erosion. The diagram shows only some of the possible configurations; other configurations may have different impacts.

C can be determined as an average value during various stages of crop culture. Tabular values are listed in Table 11. Because *C* is a ratio, the tabular values are valid for all unit systems. *C* values between two tabular points within a growing season can be interpolated. However, note that sharp changes in *C* can occur immediately after field preparation and after harvest.

Daily values of *C* can be computed from empirical equations. One possible approach is that of the Erosion Impact and Productivity Model (EPIC: Williams, 1990), which divides *C* into three subfactors (Mutchler et al., 1982):

$$C = PLU \times CC \times SR \times RC \qquad (25)$$

where

PLU = the prior landuse subfactor,

CC = the crop-canopy subfactor,

SR = the subsurface-roughness subfactor, and

RC = the residue-cover subfactor.

Detailed computation of the above subfactors requires substantial data collection efforts, which are beyond the scope of this report. However, we refer interested readers to Williams (1990) and Renard (1992) for further details.

Table 11. List of the USLE Crop-Management Factor *C* During Different Stages of Various Cropping Cycles

continued

Table 11 (continued)

continued

Table 11 (continued): Explanation of Terms

2.2.3.5. *P*, the conservation-practice factor:

Also known as the "contouring factor," *P* incorporates the effects of contouring, strip cropping (alternating crops within the contour), and terracing. The direction of tillage significantly influences erosion and sediment yield. Rules-of-thumb are that:

- Contouring reduces by one-half the soil loss caused by along-slope hill farming;
- Strip cropping reduces by one-half the soil loss associated with contouring alone; and
- Terracing further reduces by one-half the soil loss of strip cropping.

Contour furrows can store most rainfall in excess of soil water storage for small storms. Large storms may exceed furrow storage and cause breakover of ridges, resulting in more erosion and sediment yield from subsequent small storms than may have occurred without contouring. Contour tillage loses its effectiveness for long slopes or as the slope steepens. Guidelines for *P* based on slope length and steepness are reproduced from Wischmeier and Smith (1978) in Table 12. If an overland flow slope-length exceeds the "maximum length" shown in the table for any slope range, *P* should be set to 1.0 (Knisel, 1993).

Table 12. *P* for Various Slopes and Maximum Slope Lengths

Slope % From	Slope % To	*P*	Maximum length (m)
1.0	2.0	0.6	122.0
3.0	5.0	0.5	91.0
6.0	8.0	0.5	61.0
9.0	12.0	0.6	36.0
13.0	16.0	0.7	24.0
17.0	20.0	0.8	18.0
21.0	25.0	0.9	15.0

2.2.4. Nutrients and Chemical Loading

Numerous chemical and biological reactions occur within the soil-plant-hydrosphere-atmosphere (SPHA) system. Crops respond to the presence of nutrients within the SPHA in many different ways. Similarly, the fate of nutrients (i.e., quantity and deposition site) is controlled by the interactions within the SPHA. These interactions are complex, and involve the constant transformation of nutrients from one chemical form to another.

Nitrogen and phosphorus cause the bulk of water quality problems. Figure 10 demonstrates the numerous forms nitrogen can assume, together with the many transformations and pathways among these forms. The extent to which one form or another occurs and the process involved is determined by the SPHA system. Similar statements can be made with respect to the slightly simpler phosphorous cycle.

Figure 10 shows that nutrients can reach streamflow in either soluble or insoluble form. They can also reach surface waters through attachment to soil particles. The affinity of various nitrogen and phosphorous forms to attach to soil particles varies, with nitrate (NO_3) having the least and orthophosphate (PO_4) having the highest affinities.

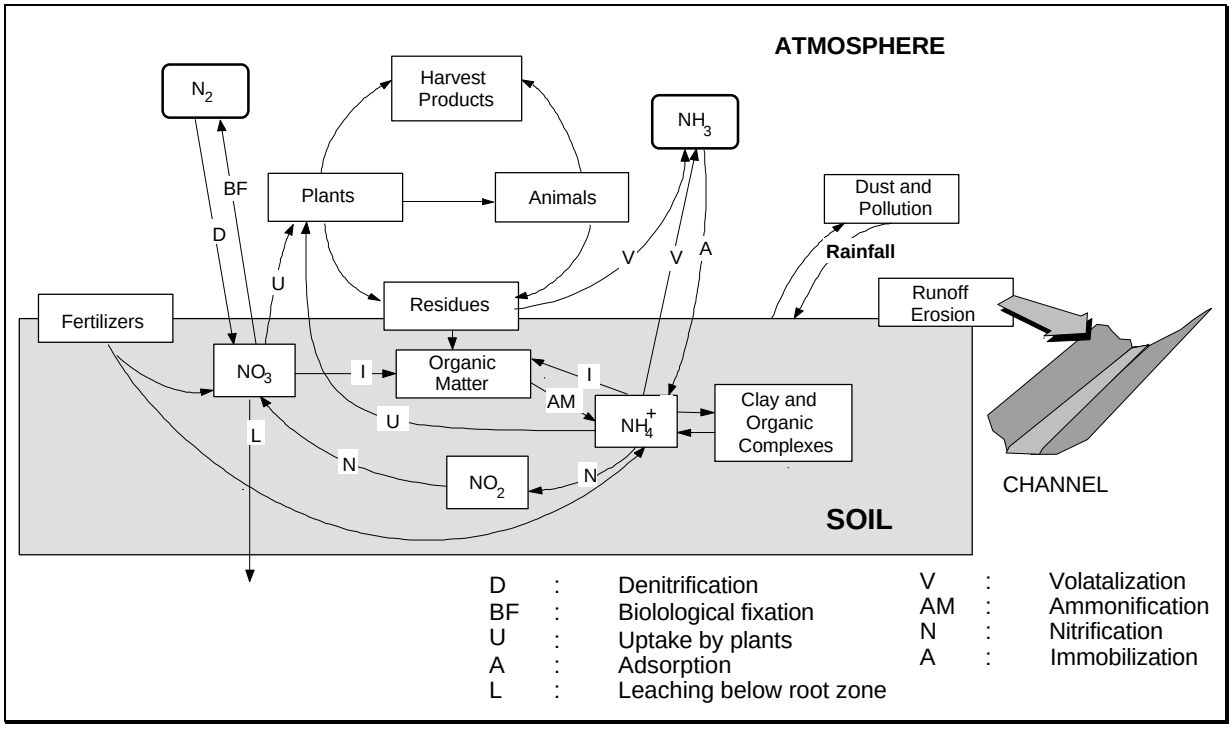


Figure 10. The nitrogen cycle within the soil-plant-atmosphere system (reconstructed from Frere and Leonard, 1982). The chemical and biochemical reactions depicted in the diagram occur simultaneously, making a quantitative assessment of the nitrogen cycle a formidable task.

Factors affecting the nitrogen cycle include soil type, temperature, tillage system, moisture, vegetation type, and fertilizer amount and form. The external sources of nitrogen and phosphorus to the soil-plant system are rainfall, atmospheric fixation (nitrogen only), and application of fertilizers. Important internal sources are the decomposition of organic material, soil mineral weathering, and chemical desorption (the release of nutrients bonded to soil particles). Nutrients in soluble form are considered to be fully available to plants. On the other hand, only small amounts of insoluble nutrients are available to plants, an amount that is controlled by factors such as soil pH, temperature, and the soil's oxidation-reduction status. For nitrogen, important soluble forms are NO_3, ammonium (NH_4), and soluble organic nitrogen. For phosphorus, the important soluble forms are PO_4 and soluble organic phosphorus. Figure 11 depicts the relationship of crop response to available nutrients. Note that there is an optimal range that is determined by climate conditions, soil, and – above all – genetically-determined plant physiology.

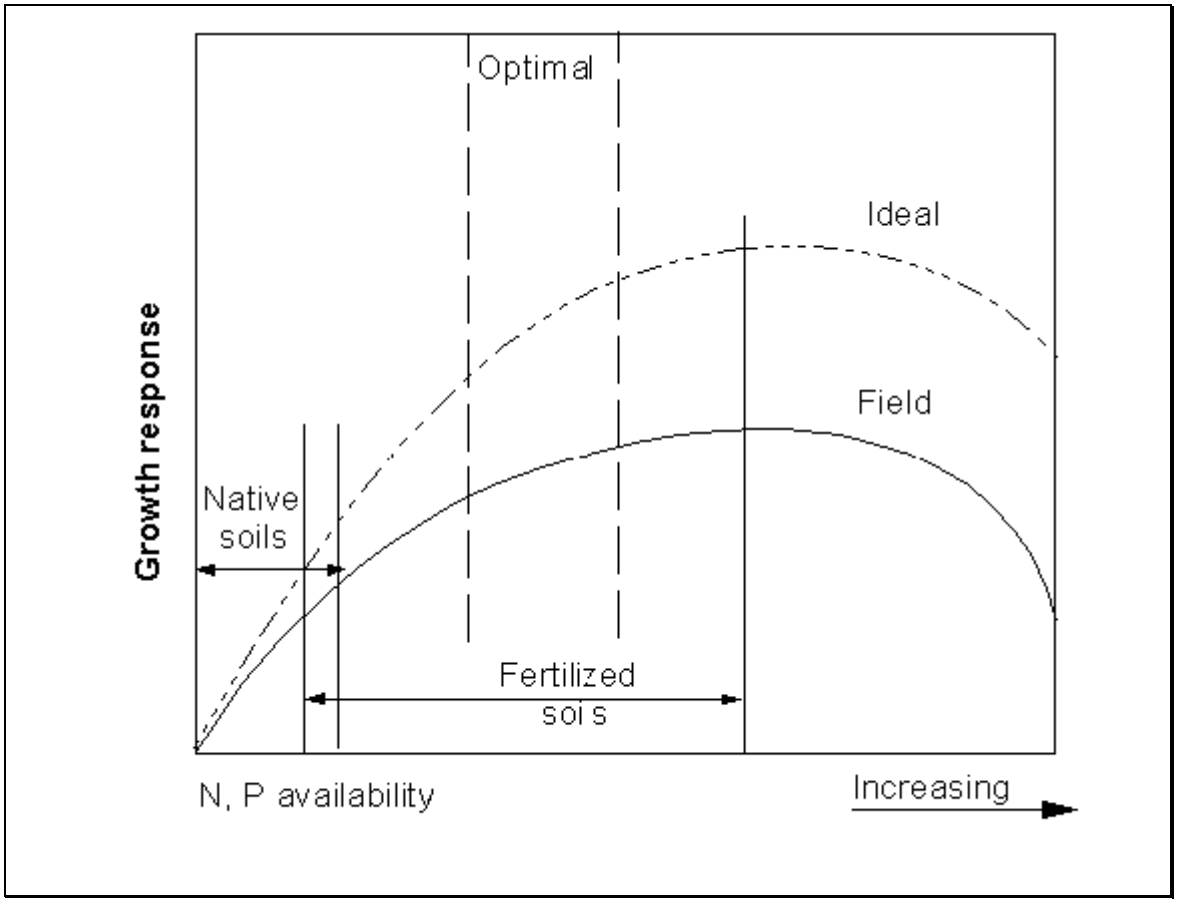


Figure 11. Plant response to nutrient availability (after Florida water quality management circular). Note that after a certain increase in availability, plant growth begins a downward decline. The optimal fertilization range is determined by economic and environmental factors, and does not encompass the maximum response.

Estimating nutrient movement requires establishing mathematical models for each of the sources and sinks of Figure 10. The process is highly dynamic, and continuous simulation models may therefore be required. At this stage of the monitoring activities in Malawi, such efforts are premature. Establishing the capability to monitor and measure soil nutrient content in fields and the nutrient content of sediments is more important. Sediment nutrient measures diagnostic studies to determine the impacts of various management systems on the presence of nutrients in surface runoff. Continuous simulation models, which must be calibrated for each management system, can subsequently be used to extrapolate and project long-term impacts. However, the results of any simulation study must be subjected to statistical analysis in order to determine the reliability of the experiment, topics that are beyond the scope of this report.

3. Results of the Data Collection Experiments

Although this document serves primarily as a field manual for initial analysis of hydrologic and water quality records, we decided to include the results of the first year's data collection campaign at one of the MEMP sites for training purposes. In so doing, we will illustrate appropriate analytical methods as well as the data adjustment and filtering techniques. ("Data adjustment" refers to the series of corrective actions required due to inaccuracies introduced by the data-collection infrastructure.) Additionally, we make comparisons between the hydrologic and environmental impacts of different farm-management systems. Chapters 3 to 5 present a step-by-step guide aimed at providing MEMP staff with the necessary tools to use these techniques – and to improve them as local conditions may dictate.

3.1. Study Site Description:

Malawi is a long, narrow country, about 840 km in length and with a maximum width of 160 km. Malawi's average elevation is about 1,200 m, with a maximum elevation of 2,600 m in the north and 3,000 m in the southern Shire Highlands. The county has a single drainage system (Figure 12). Streams flowing from the highlands drain into Lake Malawi, the third largest lake in Africa. The lake's outlet flows into Malawi's major river, the Shire River, which joins the Zambesi River at Malawi's southern border. The country's climate is subtropical, with orographic effects important at higher elevations. Average annual temperatures range from 19°C in the northern highlands to 26°C in the Shire River valley in the southern sector of the country. Similarly, the average annual rainfall varies from 1,500 mm in the north to 850 mm in the south. In both areas, a dry, cool season spans the period from May to October. This is followed by a warm, wet season from December to March. It is during this wet season that most of Malawi's agricultural activities occur.

The Chilindamaji Watershed study site is located near Nkhata Bay in the central part of the country (refer to Figure 1). Four field pits and three erosion-control plots were installed on the watershed for the purpose of collecting runoff, sediment, and water-quality data. (Figure 13 shows the relative locations of the four field pits and the three erosion-control plots.) In addition to the runoff-sediment collection pits, there is a single recording raingage in the watershed. The collected records represent the hydrologic and environmental responses to agricultural practices associated with two main crops, burley tobacco and maize. Agricultural activities on the field pits' associated plots are representative of traditional farming methods. Two of the three erosion control plots represent management activities that are designed to minimize soil loss and nutrient loading under the same cropping conditions. The third erosion control plot was left in fallow condition. Whereas the control plots were managed by MEMP staff who were trained in soil conservation practices, the four field plots were managed by the local farmers themselves. Each farmer was also responsible for both reporting the runoff measurements and for collecting the water and sediment samples for subsequent analysis by MEMP staff.

One of the major advantages of the experimental setting in Chilindamaji watershed is the simplicity of its infrastructure. The simpler the design, the easier it is to maintain and operate, especially important when excessive runoff events can cause extensive damage to the data-collection apparatus. Figure 14 is a schematic diagram of the erosion-control and the field plots; dimensions are listed in Table 13. In both cases, runoff is collected in a pit that has been dug in the soil and lined with bricks to prevent leaching losses of collected runoff water. Each runoff collection pit has a vertical ruler to measure the depth of accumulated runoff. Water and sediment samples are collected after each storm for analysis of water quality. The pit is then emptied in preparation for the next storm. It is important to realize that while the control plots are clearly delineated microcatchments, the field plots are essentially unconfined; their contributing area is delineated only by field topography and the shape of their bounding ridges.

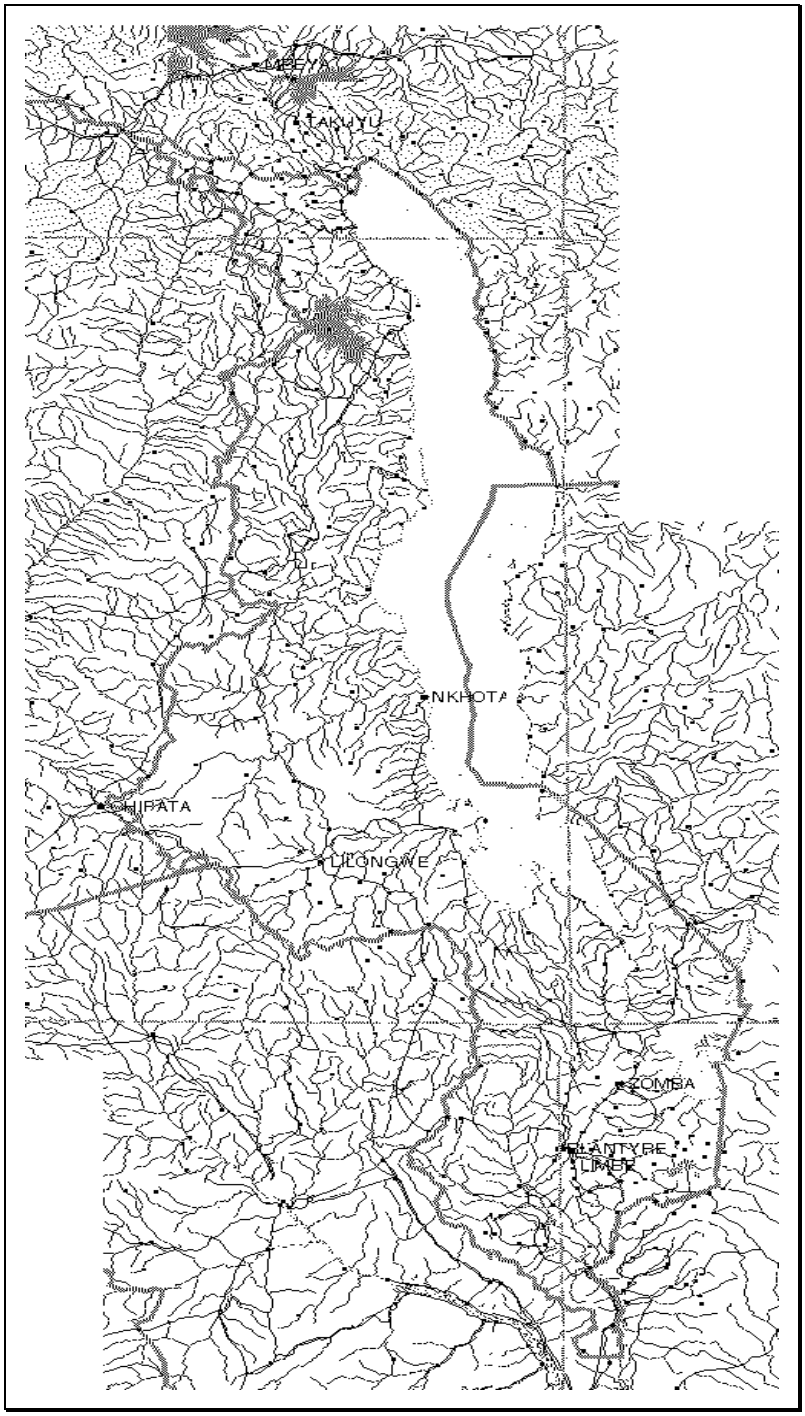


Figure 12. The drainage system of Malawi.

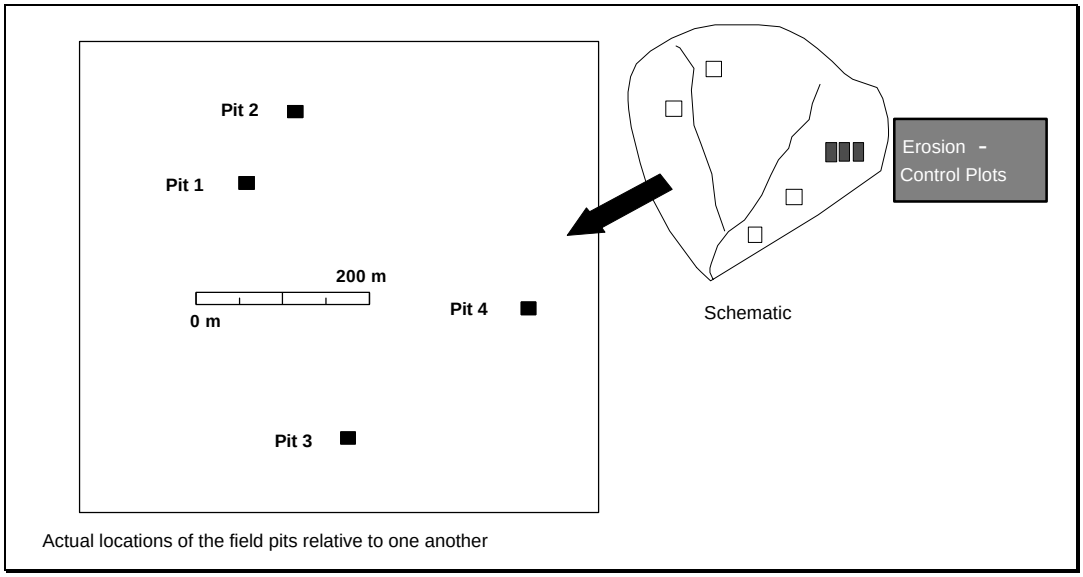


Figure 13. Actual locations of the field pits relative to one another in Chilindamaji Watershed.

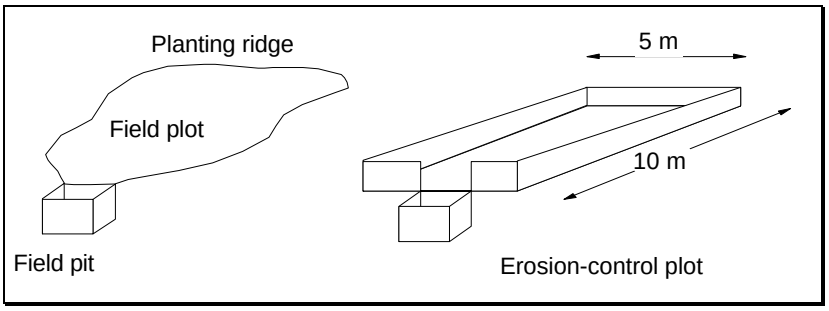


Figure 14. Schematics of field plots/pits and erosion-control plots.

Table 13. Configuration of Field Pits and Erosion-Control Plots in Chilindamaji Watershed

Pit/Plot No.	Crop	Contributing area			Collection pit	
		Length, m	Breadth, m	Area, m^2	Area, m^2	Depth, m
Field Pits						
1	Burley Tobacco	7.20	2.40	17.28	1.00	1.00
2	Maize	12.40	2.40	29.76	1.20	1.00
3	Maize	8.80	2.40	21.12	1.00	1.00
4	Burley Tobacco	3.20	5.20	16.64	1.00	0.70
Erosion-Control Plots						
B	Burley Tobacco	10.00	5.00	50.00	1.00	1.00
M	Maize	10.00	5.00	50.00	1.00	1.00
F	Fallow	10.00	5.00	50.00	1.00	1.00

3.2. Rainfall Data

As mentioned in Section 3.1, the rainfall record was obtained through a single raingage located in the watershed. However, rainfall was reported only for events associated with measurable runoff – and even then, the record is incomplete. Because complete and independent daily rainfall data were not available, and to ensure consistency among all seven collection pits, all available rainfall events were combined to obtain the total rainfall record for the period January 1 to May 1, 1995. Figure 15 shows a daily precipitation time-series, while Figure 16 is a monthly summary of rainfall.

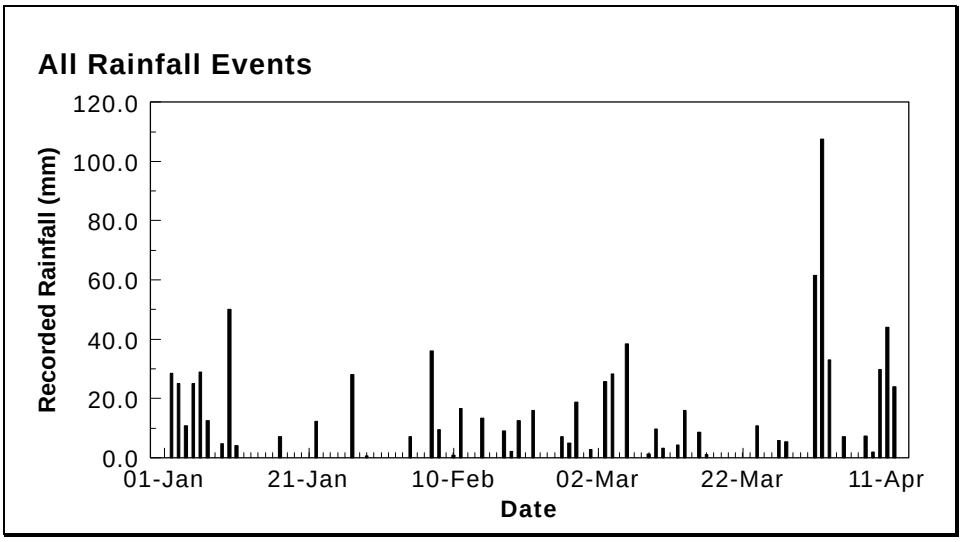


Figure 15. Daily precipitation time-series for Chilindamaji Watershed.

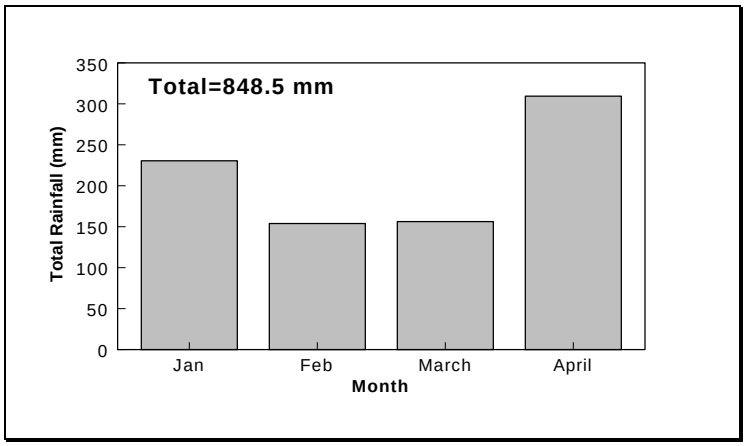


Figure 16. Total monthly precipitation for Chilindamaji Watershed.

3.3. Conversion of Units and Data Correction

3.3.1. Runoff Measurements

Runoff data are reported as pit water depth, and must be converted into an equivalent depth of water over a unit area of the contributing microcatchment. Such normalization is essential for comparing the hydrologic responses of catchments of different areas. For example, a large catchment will produce a large amount of runoff volume; a smaller catchment, which may produce a smaller total runoff, may actually have a greater volume of runoff per unit area than the larger catchment.

Steps to compute runoff depth over a unit contributing area:

In the following analysis, the subscript *p* stands for "pit," while the subscript *c* refers to a catchment.

Step 1 Convert the water depth in the pit from mm to m.

$$d_p(\mathrm{m}) = \frac{d_p(\mathrm{mm})}{1000(\mathrm{mm/m})} \tag{26}$$

Step 2 Covert the water depth d_p(m) into a volume of water in the pit.

$$V_p(\mathrm{m}^3) = d_p(\mathrm{m}) \times A_p(\mathrm{m}^2) = d_p(\mathrm{m}) \times L_p(\mathrm{m}) \times B_p(\mathrm{m}) \tag{27}$$

Where A_p, B_p, and L_p are the area, breadth, and width of the pit, respectively.

Step 3 Knowing that the volume in the pit was collected from the catchment, it is clear that $V_p = V_c$. Therefore, dividing the volume of water collected in the pit by the area of the contributing catchment converts the latter volume into a thin layer of water uniformly distributed over the contributing area.

$$d_c(\mathrm{m}) = \frac{V_p(\mathrm{m}^3)}{A_c(\mathrm{m}^2)} \tag{28}$$

Step 4 Finally, convert the depth in m over the contributing area into mm by multiplying it by 1000.

$$d_c(\mathrm{mm}) = d_c(\mathrm{m}) \times 1000 \tag{29}$$

Example: Pit 3

Consider a runoff event that collected 238 mm of runoff in the pit.

Step 1 d_p(m) = 238(mm)÷1000 = 0.238(m)

Step 2 $V_p(\mathrm{m}^3) = 0.238(\mathrm{m}) \times 1.00(\mathrm{m}^2) = 0.238(\mathrm{m}^3)$

Step 3 $d_c(\mathrm{m}) = 0.238(\mathrm{m}^3) \div 21.12(\mathrm{m}^2) = 0.01126(\mathrm{m})$

Step 4 $d_c(\mathrm{mm}) = 0.01126 \times 1000 = 11.26(\mathrm{mm})$

3.3.2. Concentration of Chemicals and Sediments

Results of laboratory chemical analyses are usually reported in mg/l, a unit important for toxicological studies and for water-quality policy guidelines. However, when comparing the amount of soil and nutrient lost from fields under different cultural practices, a unit of kg/ha is more practical. To convert concentrations from mg/l to kg./ha requires the following inputs:

1. Concentration (mg/l);
2. Total volume of the water from which the sample was taken (l); and
3. Area of the catchment producing the concentration being measured.

Since runoff is reported in mm, Equations (26) and (27) can be used to convert the water from units of depth into units of volume. The complete procedure is as follows:

Step 1 Convert water depth in the pit to volume (m^3) using Equations (26) and (27).

Step 2 Convert the volume into liters.

$$V_p(\mathrm{l}) = V_p(\mathrm{m}^3) \times 1000 \tag{30}$$

Step 3 Convert concentrations (mg/l) to total mass (kg) using the conversion factor 1 kg = 10^6 mg.

$$\text{Mass (kg)} = \frac{\text{Concentration}(\mathrm{mg/l}) \times V_p(\mathrm{l})}{1 \times 10^6} \tag{31}$$

Step 4 Convert the mass (kg) to mass per unit area (kg/ha) using the conversion factor 1 ha = 10^4 m^2.

$$\text{Loss fom catchment } (\text{kg / ha}) = \frac{\text{Mass } (\text{kg})}{\left[\dfrac{\text{Catchment area } (\text{m}^2)}{1\times 10^4}\right]} \qquad (32)$$

Example

The 238 mm runoff event was associated with 2,600 mg/l of sediment particles.

Step 1 V_p(m3) = 0.238(m^3)

Step 2 V_p(l) = 0.238×1000 = 238(l)

Step 3 Mass (kg) = (2600×238)÷(1×10^6) = 0.6188(kg)

Step 4 Loss from catchment (kg/ha) = (0.6188)÷(21.12÷(1×10^4)) = 293 kg/ha

3.4. Data Adjustment and Quality Monitoring

3.4.1. Data Adjustment

Because the runoff collection pits are uncapped, they also collect the amount of rain falling directly into the pit itself, introducing an additive error into the runoff. Furthermore, chemical concentrations are also diluted by this additional water. The additional increment may be insignificant for large catchments. However, it is best to adjust for the excess water, since (a) we know the area of the field plots, and (b) runoff is normally a fraction of the total rainfall. Consider Figure 17, which illustrates the conceptual framework for the adjustment.

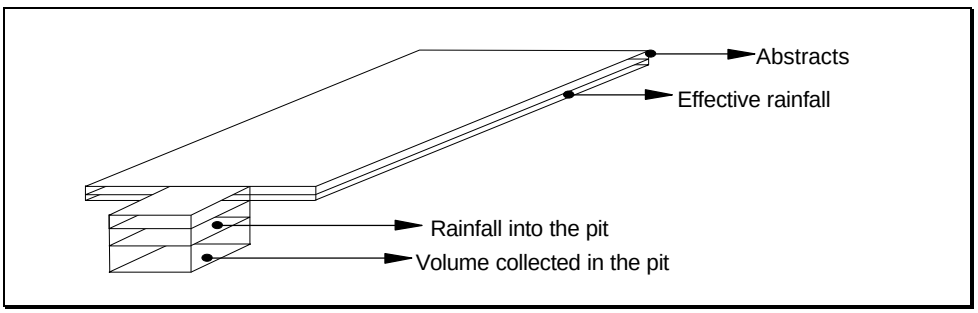


Figure 17. Conceptual framework for runoff depth-adjustment. Rainfall on the field is divided into abstracts (infiltration) and effective rainfall (runoff). The effective runoff is collected in the pit. Additionally, rainfall into the pit is fully collected without abstract. The total volume in the pit represents the sum of rainfall into the pit plus runoff from the catchment.

The first step of the data correction procedure requires adjusting the runoff depth. This is performed by simply subtracting the rainfall amount from the total depth of water in the pit. If the resulting value is greater than zero, it is considered to be the actual runoff depth. If the value is less than zero, a value of zero runoff is set. At times, a conceptual problem will exist with this procedure; a "zero" value for runoff can be obtained while concomitantly a sediment record exists for the event. In this case, the actual rainfall depth on the catchment may be different from that recorded at the raingage. This is not an uncommon occurrence, and is a consequence of the spatial variability of rainfall rates and amounts. In the absence of a rainfall record over each of the microcatchments, the runoff event must still be discarded in the rainfall-runoff analysis.

The concentration of chemicals is also adjusted by computing the runoff volume after and before adjustment. A corrected concentration is then obtained by using Equation (33).

$$\text{adjusted concentration} = \frac{\text{measured concentration} \times \text{measured volume}}{\text{corrected volume}} \quad (33)$$

Note that there is no need for concentration adjustments using Equation (33) if the mass of a chemical substance was computed based on measured runoff values. However, if the mass was not computed prior to runoff adjustments, the concentration must be corrected using Equation (33). Because the width of the pit remains constant throughout its depth, Equation (33) can be rewritten as:

$$\text{adjusted concentration} = \frac{\text{measured concentration} \times \text{measured depth}}{\text{measured depth} - \text{rainfall}} \quad (34)$$

Example

Consider a rainfall event measured at 53 mm, and an associated pit water depth of 238 mm as before. The sediment concentration is again 2,600 mg/l. Pit 3 has an area of 21.12 m^2 (Table 13).

Adjusted pit depth (mm) = 238 – 53 = 186 (mm)

Adjusted concentration (mg/l) = (2600×238)÷186 = 3326 (mg/l) [Equation (33)]

Runoff volume (m^3) = 186÷1000 = 0.186 (m^3) [Equation (30)]

Runoff depth (mm) = (0.186÷21.12)×1000 = 8.81 (mm) [Equations (28), (29)]

Adjusted sediment mass = (3326×186)÷(1×10^6) = 0.6188 kg, the same as above [Equation (31)]

Loss from catchment (kg/ha) = 0.6188÷(21.12÷(1×10^4)= 293 kg/ha, the same as above [Equation (32)]

Of course, data adjustments would not be necessary for covered pits, which do not collect direct rainfall.

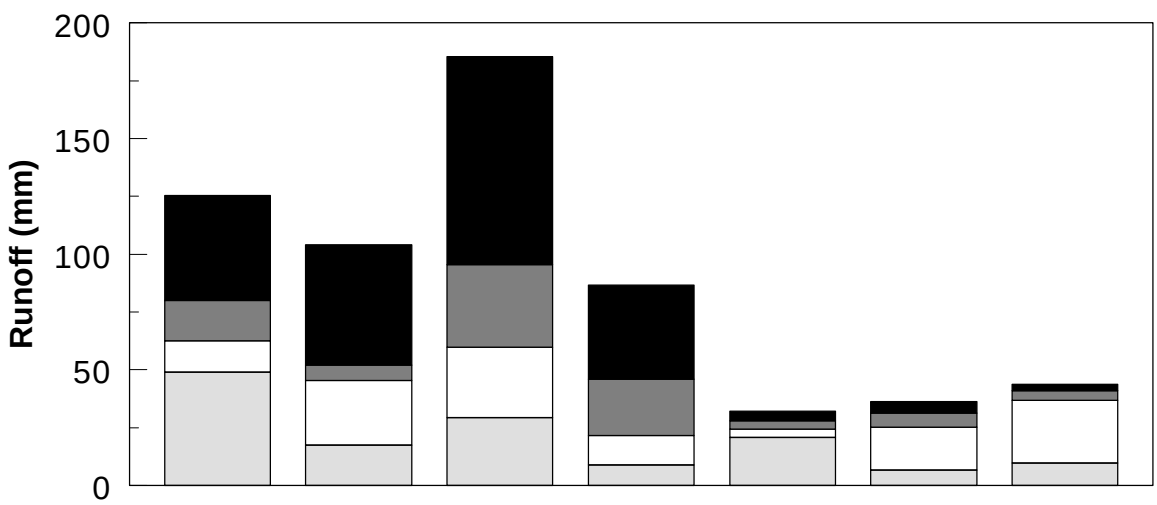
3.4.2. Data Quality:

Data quality control is a necessary component of any research program. After adjusting runoff and converting the adjusted runoff into depth over the entire catchment, MEMP staff must monitor the quality of data. A rule-of-thumb applying to catchment runoff events is that the adjusted runoff depth should not exceed the rainfall amount. If such is the case, the event must be discarded. Runoff depth exceeding rainfall amount may be due to several factors, such as seepage from subsurface flow into the pit, reporting more than one runoff events as a single event, and errors in delineating the catchment size. MEMP staff should monitor the persistence of such errors and attempt to identify (and eliminate) their cause as early as possible.

4. Data Analysis

4.1. The Runoff Record and Rainfall-Runoff Relationships

The procedures outlined in Section 3.2 were used to isolate reliable rainfall-runoff events for the four field plots and the three control plots. Figure 18 illustrate the monthly summary of the runoff values from the seven different pits. The tabulated values represent both adjusted and filtered data; filtering data consists of the removal of events because of ridge failure, baseflow measures, or other problems causing false data readings, and is discussed in detail in Section 4.2.1.



	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	48.91	17.36	29.46	8.89	20.87	6.53	9.67
Feb	13.64	28.07	30.26	12.69	3.45	18.62	27.11
March	17.40	6.71	35.78	24.60	3.74	6.13	4.33
April	45.65	52.13	90.01	40.75	4.00	5.00	2.80
TOTAL	125.60	104.27	185.51	86.93	32.06	36.28	43.91

Figure 18. Comparison between monthly and total runoff values for different farm management systems in Chilindamaji Watershed. Note the large difference between the runoff generated from the field plots versus the three control plots.

Curve number values were estimated using two methods. The first method is the HHZ approach (see Section 2.1.3.2.2). As previously stated, the HHZ method may not work for all watersheds or plots. In our analysis for the seven different pits in Chilindamaji, HHZ yielded CN values only for the four field plots. Control plots display a weak rainfall-runoff relationship, preventing the identification of an HHZ CN value. The second method is a similar computation, but with all of the runoff-producing rainfall events considered in order (refer to Table 3), and is presented because cases exist where even 30 years of continuous data have not resulted in an HHZ-derived CN. This average-S based CN was computed for all four pits and three plots. Clearly, such a number is not a reliable estimate because it tends to emphasize small rainfall events, giving rise to higher CN values. In all cases, the availability of only a single year of data makes the task of identifying a clear rainfall-runoff relationship rather uncertain. Furthermore, error in collected data, such as recording higher runoff volume than the available precipitation, resulted in the elimination of a

considerable number of events from the analysis. Figure 19 shows the differences in CN obtained by both methods of calculation.

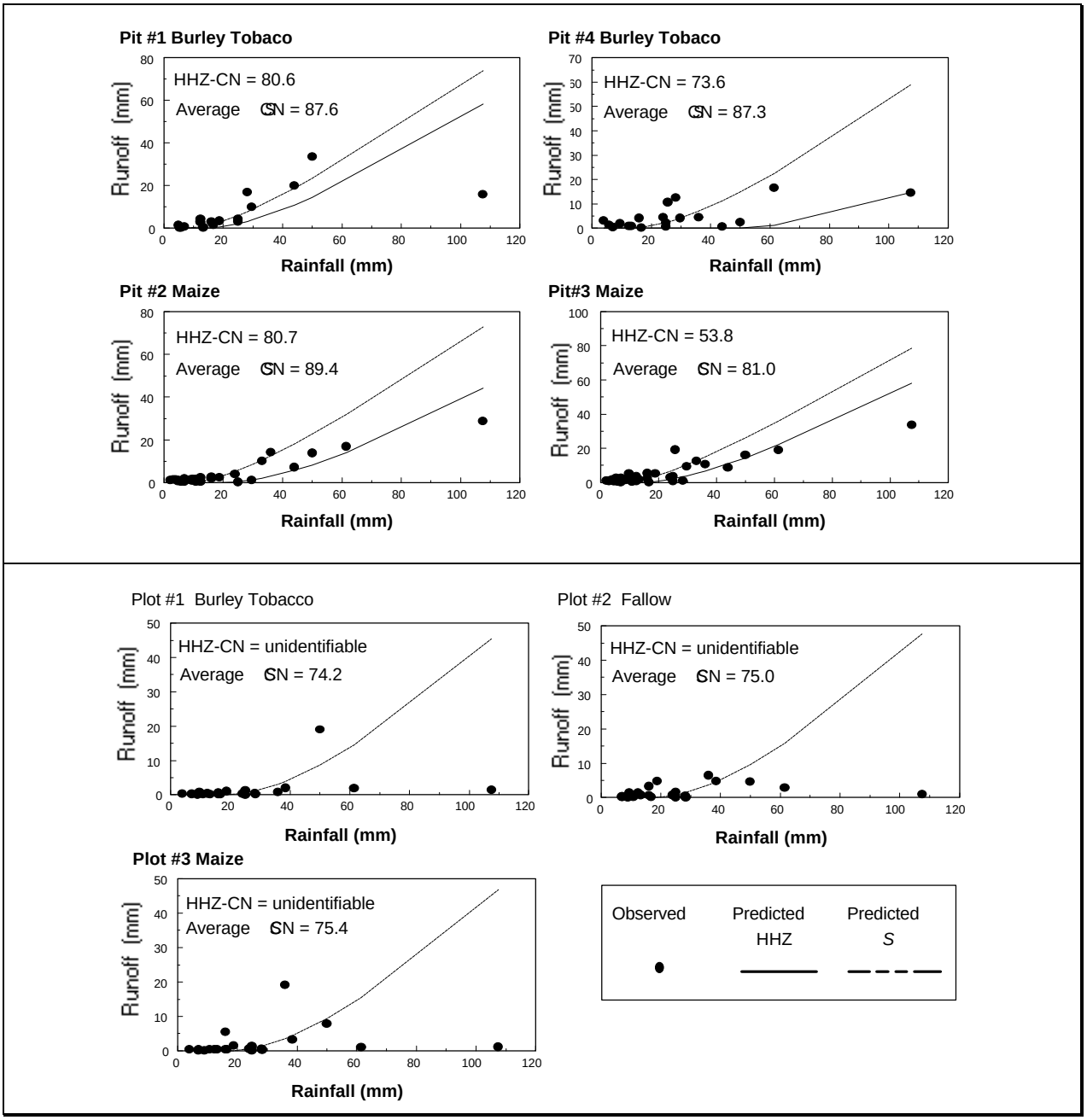


Figure 19. Rainfall-runoff relationships for the four field plots (top) and the three erosion-control plots (bottom) in Chilindamaji Watershed, January – April, 1995. Note that values for the erosion-control plots are significantly lower than those for field plots with the same crop cover.

Because of the short period of record, determining CN using either method may not be reliable and indicative of the catchment response under different crop conditions. A possible method to discriminate among different management practices with respect to their rainfall-runoff relationship in a watershed is to graph *P* against CN (computed from the running average, as in Table 3), shown in Figure 20. For each of the seven plots, the graph was constructed from the following steps, which are similar to those used in the HHZ-CN approach but without using the $P/S>0.456$ condition.

Step 1 Arrange the runoff-producing rainfall events in descending order.

Step 2 For each event, compute S from Equation (16).

Step 3 For each event (i), compute a running-average value of S from Equation (35):

$$\overline{S_i} = \frac{\sum_{j=1}^{i} S_j}{i} \tag{35}$$

where

$\overline{S_i}$ = the ith event running-average storage parameter,

S_j = the jth event storage parameter,

In Equation (35) the following condition must be satisfied:

$$P_1 > P_2 > .... > P_j > .... > P_i \tag{36}$$

(Equation (36) represents the listing of rainfall events in descending order.)

Step 4 Once $\overline{S_i}$ is obtained for each event, compute the corresponding $\overline{\mathrm{CN}}_i$ from Equation (9).

Step 5 Finally, graph each rainfall value P_i against the corresponding $\overline{\mathrm{CN}}_i$.

By repeating the same process for each of the seven plots, and graphing P on the x-axis and $\overline{\mathrm{CN}}_i$ on the y-axis, a diagnostic chart is created that can be used to evaluate the effects of different cropping regimes on the catchments' rainfall-runoff relationships. Figure 20, for example, indicates that under similar rainfall conditions, areas planted with maize and managed using traditional methods (solid and open diamonds) produce higher runoff than those areas planted with burley tobacco and managed using traditional conditions (solid and open circles). This difference is greatest for large rainfall events. For smaller rainfall events, however, the response of one of the burley field pits (Pit #1, solid circles) resembled that of both maize plots. Several factors may have contributed to this similarity, among which are the farmers' different land management regimes, soil spatial variability, topography, and rainfall rates. Finally, Figure 20 clearly shows that the three control plots have similar rainfall-runoff relationships, ones characterized by runoff substantially lower than obtained from the field plots, which conclusively demonstrates the effectiveness of erosion-control practices in reducing runoff from fields.

4.2. Water-Quality Data Analysis

4.2.1. Introduction

Water-quality data were obtained from the pits following each runoff-producing storm. Samples were collected after stirring the accumulated water in the pits, and sent for laboratory analysis. Results were reported in units of mg/liter.

Mismeasurements and missed measurements of runoff events are the two main causes of reduced sample size. Other problems are the consequences of some extreme rainfall events. On several occasions during the first monitoring season, extreme rainfall events damaged some of the ridges, caused pit overflow, and delayed the process of data collection. Ridge damage is the most problematic for both water quality in general, and for the identification of the impact of management practices on the erosion characteristics of the catchment. Ridge failure caused substantial quantities of sediments to be dislodged, transported, and deposited into collection pits. Such failures must be excluded from the dataset, especially when the catchment area is small, as is the case for the four field plots. There are four reasons for excluding these events from the record:

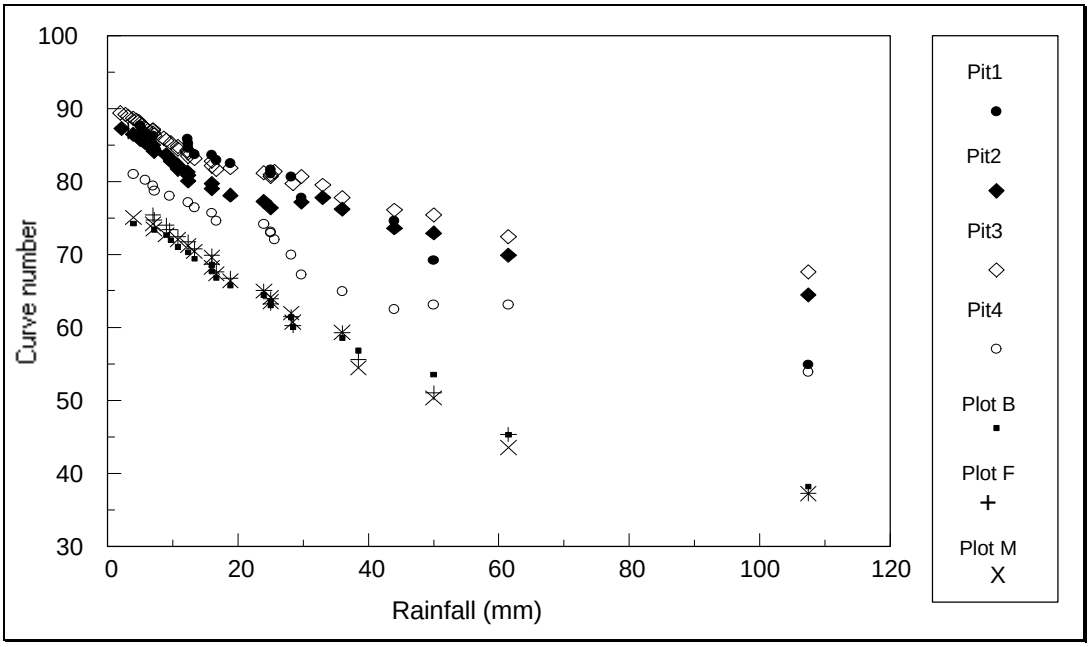


Figure 20. A comparison of rainfall-runoff relationships between traditional cropping systems and management systems that aim to control erosion. The plot should not be viewed as a predictive tool, but it can be used as a diagnostic tool. Note the significant reduction of runoff as indicated by lower CN values for the same rainfall values associated with the three erosion-control plots. These have near-identical responses, especially under high rainfall conditions – precisely the conditions that produce most of the erosion in traditional management systems.

1. In natural fields, sediments detached from damaged ridges may be deposited on milder slopes prior to reaching the field outlet; sequential ridges or terraces also obstruct sediment transport.
2. Although ridges are integral components of some crop-management systems and must be included in calculations of total soil loss, ridge failure represents a dynamic process that is as much related to soil stability as to soil erosion properties.
3. Given that the contributing areas of the four field plots in Chilindamaji Watershed are delineated by ridges, partial or complete ridge failure is associated with changes in the size of the catchment; consequently, runoff estimates become inconsistent.
4. Most erosion prediction models do not account for ridge failure when calculating the total amount of sediment yield during a fixed period. Instead, the failure process is usually modeled qualitatively, i.e., runoff depth and velocity are calculated from hydraulic equations. If these values exceed ridge tolerance, a failure event is registered. However, these models do not compute the amount of eroded soil.

For this study, we used the following criteria to select an acceptable subset of events for water-quality impact assessment. Table 14 lists all excluded events; Table 15 lists water-quality parameters for all included events.

1. All events for which *Q* exceeded *P* were excluded from the sample.
2. Days that were associated with ridge failure on any field or control plot were excluded from the record of *all* plots. This is necessary to maintain consistency when comparing the water-quality impacts of burley tobacco versus maize. (Note that some of these events, such as Incident 5, produce an extremely high value of soil loss/unit area.)

Table 14. Excluded Runoff Events, Chilindamaji Watershed, Jan. - Apr., 1995

Incident	Month	Day	Plot	Crop	Soil Loss (kg/ha)
1	January	28	1	Burley tobacco	218.92
2	January	29	1	Burley tobacco	Unrecorded/error
3	April	5	1	Burley tobacco	1043.11
4	April	10	1	Burley tobacco	3495.00
5	April	1	2	Maize	6470.36
6	March	3	3	Maize	Unrecorded/error
7	March	4	3	Maize	Unrecorded/error
8	April	1	3	Maize	135.04
9	February	4	M	Maize	97.62
10	February	7	M	Maize	354.42

Table 15. Water-Quality Parameters for Included Events, Chilindamaji Watershed, Jan. - Apr., 1995

TDS: Total dissolved solids (including salts)
SO_4: Oxidized Sulfates (soil, rainfall)
NO_3: Nitrate (from soil, rainwater, and fertilizers)
SO_4: Orthophosphate (fertilizers)
Na: Sodium (soil)
K: Potassium (fertilizers and soil)
Sed. Sediments (i.e., soil loss)

Pit #1 (Burley tobacco)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	7	12.4	4.49	7.5	3.65	0.56	0.0020	0.11	1.56	5.21	51.56
1	10	50.0	33.56	7.7	136.35	4.23	0.0070	1.46	16.41	25.52	266.15
2	11	16.7	1.64	6.9	3.96	0.21	0.0010	0.31	2.21	4.95	41.93
2	14	13.3	0.39	6.9	1.18	0.54	0.0000	0.04	0.46	1.27	20.83
2	19	12.4	2.75	7.0	5.28	0.37	0.0010	0.11	2.43	7.29	68.06
2	21	16.0	3.12	6.7	2.76	1.98	0.0000	0.17	2.43	7.29	117.88
2	25	7.0	0.75	7.2	2.38	0.10	0.0000	0.02	1.10	4.05	9.49
2	26	5.0	1.45	6.7	1.39	0.17	0.0000	0.05	0.52	2.60	26.74
2	27	18.8	3.54	6.9	4.91	19.35	0.0000	0.48	1.62	6.94	27.32
3	27	5.8	0.24	6.9	0.79	0.12	0.0010	0.00	1.04	1.97	1.45
3	28	5.3	0.27	6.9	0.00	0.10	0.0010	0.00	0.64	1.27	3.7
4	11	44.0	20.02	6.8	61.84	2.26	0.0020	0.09	5.64	9.03	48.07
Total		206.7	72.22	n/a	224.48	30.00	0.0150	2.83	36.07	77.4	683.17
Minimum		5.0	0.24	6.7	0.00	0.10	0.0000	0.00	0.46	1.27	1.45
Maximum		50.0	33.56	7.7	136.35	19.35	0.0070	1.46	16.41	25.52	266.15
Average		17.23	6.02	7.0	18.71	2.50	0.0013	0.24	3.01	6.45	56.93

Pit #4 (Burley tobacco)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	3	25.00	2.28	6.70	14.16	0.85	0.0000	0.01	11.17	11.93	6.06
1	5	25.00	0.60	7.00	2.31	0.12	0.0020	0.04	4.00	8.73	26.29
2	8	9.50	1.95	6.90	4.09	0.24	0.0010	0.09	2.02	4.17	73.20
2	11	16.70	0.26	7.30	2.75	0.61	0.0030	0.06	1.39	1.89	39.25
2	14	13.30	0.88	6.00	3.13	0.11	0.0120	0.08	1.77	2.10	48.13
2	19	12.40	0.94	6.70	2.46	0.24	0.0020	0.07	1.18	1.85	54.18
2	21	16.00	4.09	8.00	5.96	0.24	0.0000	0.18	2.02	4.54	72.19
3	27	5.80	1.33	6.80	1.41	0.55	0.0050	0.01	2.52	2.69	9.36
4	2	107.50	14.57	6.90	26.50	1.68	0.0080	0.40	7.36	13.67	1076.92
4	8	7.20	0.41	6.60	0.45	0.07	0.0000	0.02	0.38	0.51	10.22
4	11	44.00	0.72	6.80	0.94	2.23	0.0030	0.26	1.68	3.03	187.79
4	12	24.00	4.45	6.80	0.47	4.12	0.0060	0.02	3.53	5.89	197.00
Total		306.40	32.48	n/a	64.64	11.05	0.0420	1.23	39.02	61.00	1800.58
Minimum		5.80	0.26	6.00	0.45	0.07	0.0000	0.01	0.38	0.51	6.06
Maximum		107.50	14.57	8.00	26.50	4.12	0.0120	0.40	11.17	13.67	1076.92
Average		25.53	2.71	6.88	5.39	0.92	0.0035	0.10	3.25	5.08	150.05

Pit #2 (Maize)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	3	25.00	0.20	7.10	0.53	0.12	0.0000	0.15	0.42	1.33	81.65
1	7	12.40	0.31	8.70	3.08	0.05	0.0000	0.05	0.93	2.26	10.57
1	9	4.80	0.61	9.30	7.79	0.18	0.0000	0.03	3.79	4.92	65.00
1	10	50.00	13.71	8.90	34.28	2.61	0.0030	0.52	11.01	25.16	270.48
1	22	12.30	0.71	9.60	11.61	0.48	0.0000	0.08	6.51	14.06	16.09
2	8	9.50	0.79	6.70	1.99	0.07	0.0000	0.03	0.94	1.99	18.59
2	17	9.00	1.25	6.70	10.00	0.14	0.0000	0.07	4.36	6.37	1.29
2	18	2.10	1.13	6.90	0.03	0.10	0.0000	0.01	1.75	3.39	22.38
2	19	12.40	2.32	6.70	8.47	0.24	0.0010	0.10	3.95	7.34	58.71
2	21	16.00	2.58	6.80	5.87	0.23	0.0010	0.12	3.23	7.10	86.45
2	25	7.00	0.52	7.30	1.84	0.09	0.0000	0.01	0.89	1.86	2.42
2	26	5.00	1.01	7.00	2.71	0.17	0.0000	0.01	1.69	4.42	3.75
2	27	18.80	2.47	6.30	5.36	0.25	0.0020	0.05	1.94	3.55	3.23
3	10	9.70	1.63	6.60	4.40	0.32	0.0000	0.05	2.02	4.03	35.08
3	11	3.20	1.48	6.80	2.42	0.30	0.0000	0.03	0.16	2.74	3.23
3	14	16.00	1.77	6.70	7.60	0.24	0.0000	0.22	2.42	4.36	24.68
3	24	10.80	1.54	6.80	1.74	0.51	0.0000	0.01	2.37	2.77	13.34
3	27	5.80	0.29	6.70	0.66	0.23	0.0000	0.00	0.63	0.73	3.88
4	2	107.50	28.73	6.40	7.94	2.91	0.0100	1.95	6.61	13.23	610.04
4	11	44.00	7.10	6.80	7.98	0.89	0.0090	0.12	3.55	5.77	98.91
4	12	24.00	3.87	6.60	5.71	0.59	0.0050	0.03	2.42	3.87	17.61
Total		405.30	74.02	n/a	132.00	10.74	0.0310	3.63	61.57	121.22	1447.37
Minimum		2.10	0.20	6.30	0.03	0.05	0.0000	0.00	0.16	0.73	1.29
Maximum		107.50	28.73	9.60	34.28	2.91	0.0100	1.95	11.01	25.16	610.04
Average		19.30	3.52	7.21	6.29	0.51	0.0015	0.17	2.93	5.77	68.92

Pit #3 (Maize)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	2	28.40	1.02	7.30	1.14	1.09	0.0000	0.07	2.60	5.68	0.57
1	3	25.00	3.55	7.60	13.07	0.79	0.0000	0.23	17.99	40.72	12.31
1	4	10.80	0.44	8.80	0.19	0.44	0.0010	0.00	2.32	4.36	0.59
1	5	25.00	0.71	8.50	1.10	0.88	0.0000	0.04	4.36	8.33	0.34
1	7	12.40	3.67	6.90	0.51	1.71	0.0000	0.06	2.56	4.90	0.90
1	9	4.80	0.72	7.90	1.02	0.48	0.0000	0.02	1.80	2.75	0.17
1	10	50.00	16.10	7.10	53.18	2.22	0.0040	0.61	9.23	19.39	36.93
1	22	12.30	1.31	7.30	2.92	1.48	0.0060	0.06	4.74	9.47	0.63
2	11	16.70	0.16	6.20	1.50	0.23	0.0060	0.05	1.09	1.47	25.38
2	14	13.30	1.74	6.30	0.28	0.68	0.0010	0.07	1.54	4.03	35.18
2	17	9.00	1.94	6.30	3.93	0.38	0.0000	0.08	3.20	5.92	22.73
2	19	12.40	0.83	6.30	2.36	0.23	0.0000	0.05	1.92	3.55	13.64
2	21	16.00	5.40	7.20	6.89	0.14	0.0010	0.49	1.23	0.00	47.40
2	25	7.00	1.09	6.70	1.45	28.69	0.0000	0.05	0.36	1.28	26.42
2	26	5.00	1.18	6.10	1.85	0.17	0.0100	0.04	1.14	2.06	7.81
2	27	18.80	5.27	6.20	7.88	0.53	0.0030	0.19	0.15	3.69	50.47
3	1	2.80	0.81	6.10	2.97	0.10	0.0060	0.04	0.66	1.47	30.02
3	10	9.70	5.22	6.50	1.36	0.68	0.0020	0.13	1.71	2.84	60.23
3	11	3.20	0.89	6.30	1.60	0.08	0.0030	0.10	0.26	0.83	46.46
3	13	4.40	0.74	7.00	1.52	0.28	0.0010	0.02	0.57	0.95	7.22
3	14	16.00	2.41	6.50	2.73	0.95	0.0100	0.46	1.27	2.54	0.21
3	16	8.60	1.49	6.70	2.61	0.47	0.0000	0.02	1.14	1.42	0.09
3	24	10.80	1.86	6.80	1.23	0.24	0.0010	0.05	1.42	3.31	29.95
3	27	5.80	0.67	6.80	0.95	0.23	0.0020	0.00	1.33	2.65	6.06
3	28	5.30	2.59	6.70	1.88	0.34	0.0030	0.05	1.42	4.69	47.44
4	2	107.50	33.74	7.00	45.81	3.34	0.0020	0.62	5.82	13.59	250.43
4	3	33.00	12.64	6.60	19.03	1.42	0.0010	0.06	2.13	4.26	50.57
4	9	2.00	0.85	6.40	1.46	0.06	0.0000	0.00	0.14	0.38	4.05
4	11	44.00	8.81	6.50	16.34	0.65	0.0030	0.11	1.63	4.36	57.17
4	12	24.00	3.12	7.10	1.71	0.38	0.0010	0.07	0.85	1.28	12.53
Total		544.00	120.97	n/a	200.46	49.34	0.0670	3.82	76.56	162.15	883.86
Minimum		2.00	0.16	6.10	0.19	0.06	0.0000	0.00	0.14	0.00	0.09
Maximum		107.50	33.74	8.80	53.18	28.69	0.0100	0.62	17.99	40.72	250.43
Average		18.13	4.03	6.86	6.68	1.64	0.0022	0.13	2.55	5.41	29.46

Control Plot #1 (Burley tobacco)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	3	25.00	1.30	7.30	11.56	0.29	0.0010	0.03	4.68	9.18	7.20
2	11	16.70	0.27	7.00	0.53	0.11	0.0020	0.01	1.56	1.29	13.26
2	14	13.30	0.23	7.10	1.13	0.22	0.0000	0.02	1.08	1.05	9.05
2	17	9.00	0.12	7.00	0.86	0.08	0.0000	0.01	1.05	0.95	4.17
2	19	12.40	0.35	6.80	2.35	0.13	0.0010	0.01	1.11	1.20	9.66
2	21	16.00	0.58	6.60	2.54	0.31	0.0010	0.05	1.04	1.08	24.30
2	27	18.80	1.02	6.90	4.68	0.50	0.0010	0.05	1.96	1.89	30.52
3	10	9.70	0.81	6.80	1.24	0.14	0.0000	0.01	0.70	0.90	4.60
3	14	16.00	0.28	6.80	0.41	0.10	0.0000	0.00	1.08	0.96	2.64
3	24	10.80	0.18	6.80	0.20	0.07	0.0010	0.00	1.08	1.34	0.09
4	12	24.00	0.32	6.90	1.10	0.09	0.0000	0.02	0.28	0.32	12.72
Total		171.70	5.46	n/a	26.59	2.05	0.0070	0.21	15.61	20.16	118.21
Minimum		9.00	0.12	6.60	0.20	0.07	0.0000	0.00	0.28	0.32	0.09
Maximum		25.00	1.30	7.30	11.56	0.50	0.0020	0.05	4.68	9.18	30.52
Average		15.61	0.50	6.91	2.42	0.19	0.0006	0.02	1.42	1.83	10.75

Control Plot #2 (Fallow)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	3	25.00	1.70	7.60	10.74	0.32	0.0000	0.02	6.16	6.27	39.82
1	5	25.00	0.10	7.20	1.38	0.07	0.0000	0.02	0.84	1.41	3.48
2	8	9.50	1.41	7.20	7.23	0.36	0.0030	0.12	4.16	3.60	22.40
2	11	16.70	0.17	6.50	0.77	0.07	0.0010	0.01	0.25	0.50	5.45
2	14	13.30	0.73	7.00	0.68	0.47	0.0010	0.02	1.20	1.30	30.10
2	17	9.00	0.12	6.80	0.01	0.11	0.0000	0.01	0.83	0.60	3.93
2	19	12.40	1.35	6.70	3.55	0.00	0.0020	0.07	0.96	1.20	28.00
2	21	16.00	3.28	6.80	2.38	1.67	0.0000	0.09	1.62	2.16	33.12
4	12	24.00	0.72	6.90	0.65	0.10	0.0000	0.01	0.42	0.66	5.02
Total		150.90	9.58	n/a	27.38	3.16	0.0070	0.38	16.44	17.70	171.32
Minimum		9.00	0.10	6.50	0.01	0.00	0.0000	0.01	0.25	0.50	3.48
Maximum		25.00	3.28	7.60	10.74	1.67	0.0030	0.12	6.16	6.27	39.82
Average		16.77	1.06	6.97	3.04	0.35	0.0008	0.04	1.83	1.97	19.04

Control Plot #3 (Maize)

Mon.	Day	*P* mm	*Q* mm	pH	TDS kg/ha	SO_4 kg/ha	NO_3 kg/ha	PO_4 kg/ha	Na kg/ha	K kg/ha	Sed. kg/ha
1	3	25.00	1.30	8.40	6.84	0.45	0.0010	0.09	6.12	5.94	17.28
1	5	25.00	0.02	8.30	3.15	0.14	0.0000	0.01	2.55	2.26	1.87
2	11	16.70	0.27	6.90	2.40	0.07	0.0000	0.01	1.50	1.20	2.16
2	14	13.30	0.33	6.40	1.33	0.09	0.0040	0.03	1.56	1.35	12.18
2	17	9.00	0.02	7.00	0.50	0.04	0.0000	0.00	0.71	0.63	1.62
2	19	12.40	0.35	6.80	1.88	0.18	0.0010	0.03	1.20	1.20	16.50
2	21	16.00	5.48	5.70	17.75	0.05	0.0530	0.47	2.03	2.90	138.62
2	27	18.80	1.42	7.00	5.15	0.83	0.0000	0.05	1.89	2.07	31.14
3	14	16.00	0.28	6.70	0.83	0.08	0.0010	0.01	0.87	1.08	1.26
3	24	10.80	0.38	6.40	0.44	0.10	0.0010	0.04	1.68	2.16	0.76
4	12	24.00	0.52	7.30	6.64	0.02	0.0000	0.01	0.40	0.60	7.50
Total		187.00	10.37	n/a	46.92	2.05	0.0610	0.74	20.51	21.39	230.89
Minimum		9.00	0.02	5.70	0.44	0.02	0.0000	0.00	0.40	0.60	0.76
Maximum		25.00	5.48	8.40	17.75	0.83	0.0530	0.47	6.12	5.94	138.62
Average		17.00	0.94	6.99	4.27	0.19	0.0055	0.07	1.86	1.94	20.99

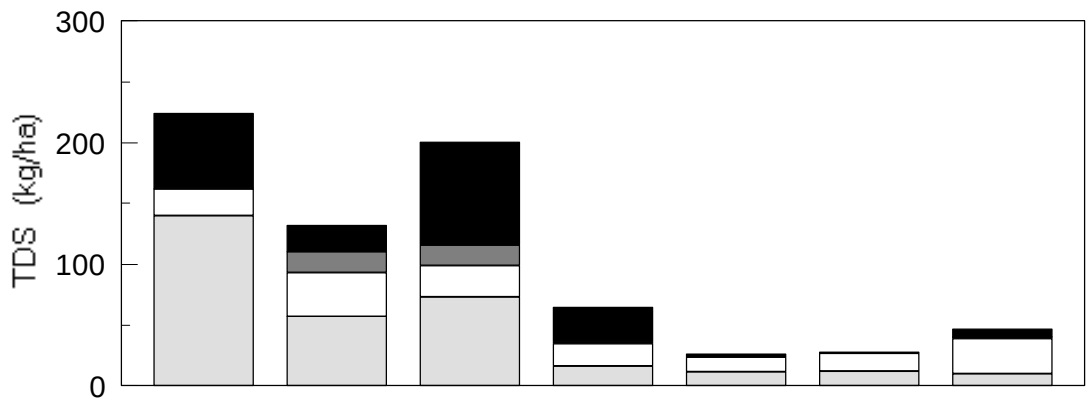
Because the available record consists of a single monitoring season, statistical analysis of the data beyond total values would lack the required level of significance. At the current stage of the monitoring efforts, therefore, we will use total values of water-quality variables to discriminate between the two management crops and the corresponding traditional versus soil-conservation practices. In the following section, we will (a) consider each of the water-quality parameters, and (b) intercompare observed values from each of the sampling locations.

4.2.2. A Comparison of Crops and Crop Management Practices

4.2.2.1. Total Dissolved Solids (TDS)

Total dissolved solids include the inorganic salts such as calcium, Ca, magnesium, Mg, and sodium, Na. The presence of large amounts of these salts in runoff indicates high soil salinity. Although Ca does not constitute direct harm, its presence in high concentrations leads to increased salinity of both surface water and groundwater. The presence of Ca in abundance is common because it is a major constituent of several mineral rocks and soils. In general, Ca can be found in runoff water with pH values from 7 to 8, a range close to many runoff events in the watershed. Acceptable limits for Ca concentration are usually based on determinations of adverse impact at the runoff's end-point, or on agreed-upon levels of salts ultimately leaching to groundwater.

Figure 21 and the accompanying table indicate total monthly and seasonal TDS values from the experimental locations in Chilindamaji Watershed. Note that the amount of TDS in surface runoff from the field plots is almost an order of magnitude higher than comparable losses from the control plots. Fallow land has the same order of TDS losses as do the two cropped control plots.

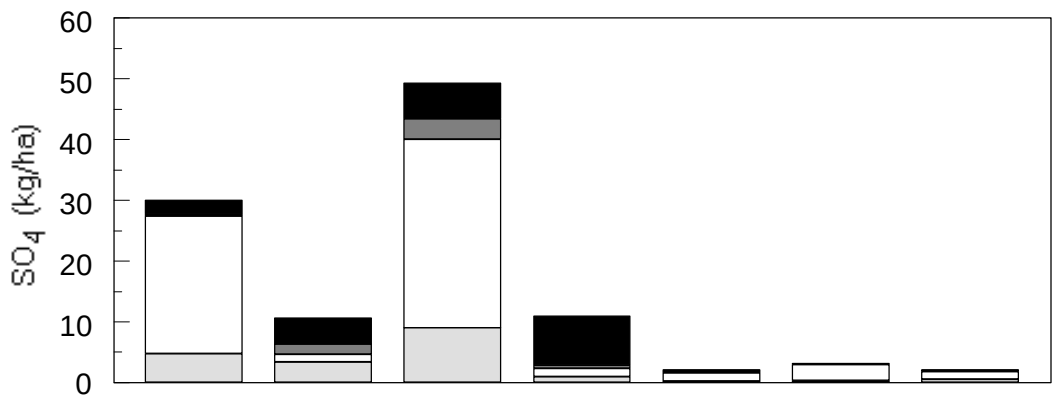


	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	140.000	57.298	73.124	16.474	11.556	12.116	9.991
Feb	21.852	36.264	26.137	18.384	12.082	14.615	29.016
March	0.787	16.810	16.851	1.413	1.848	0.000	1.272
April	61.840	21.629	84.346	28.369	1.104	0.648	6.640
Total	224.479	132.001	200.458	64.640	26.590	27.379	46.919

Figure 21. Monthly and seasonal TDS losses from field and erosion-control plots in Chilindamaji Watershed.

4.2.2.2. Oxidized Sulfate (SO_4)

The same processes that govern the presence of Ca in natural waters control concentrations of SO_4. Furthermore, SO_4 occurs in rainfall at concentrations that vary with the level of air pollution (causing the "Acid Rain" problem in industrialized countries). Under unpolluted conditions, rainwater SO_4 concentrations of around 1.0 mg/l are normal. A concentration as high as 250 mg/l is acceptable even for drinking water. Figure 22 and the accompanying table indicate total monthly and seasonal SO_4 losses from the experimental locations in Chilindamaji Watershed. Note that the concentration of SO_4 in surface runoff from the field plots is almost an order of magnitude higher than comparable losses from the control plots. Fallow land loses SO_4 in concentrations similar to those of the two cropped control plots.



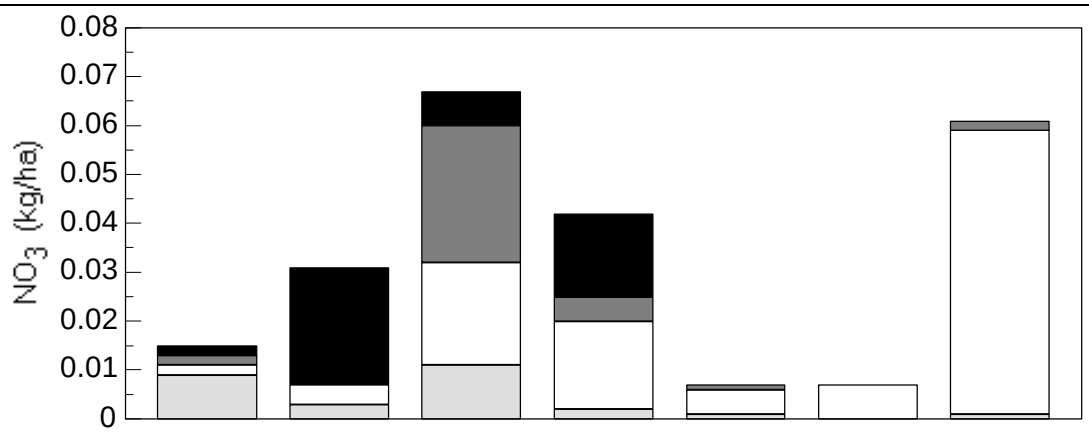
	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	4.791	3.441	9.066	0.966	0.288	0.391	0.593
Feb	22.721	1.296	31.052	1.434	1.355	2.675	1.258
March	0.223	1.614	3.382	0.552	0.316	0.000	0.176
April	2.261	4.387	5.844	8.098	0.086	0.098	0.020
Total	29.996	10.738	49.344	11.050	2.045	3.164	2.047

Figure 22. Monthly and seasonal SO_4 losses from field and erosion-control plots in Chilindamaji Watershed.

4.2.2.3. Nitrate (NO_3)

As mentioned in Section 2.2.4, NO_3 is but one of the many forms nitrogen assumes in nature. Unlike ammonium and orthophosphate, nitrate adsorption by soil particles is very low. Thus, the amount of NO_3 transported by runoff is not significant. Infiltration below the surface and to the groundwater aquifer is the fate of most soil NO_3. In surface waters, NO_3 concentrations can increase when previously infiltrated water resurfaces as baseflow.

The physical processes controlling the infiltration rate also control the rate of denitrification (the process of converting ammonia [NH_4] into nitrite [NO_2] and then to NO_3: Frere and Leonard, 1982). In sum, therefore, only low concentrations of NO_3 are lost in sediment and runoff. **However, note that NO_3 concentrations alone do not reflect the full spectrum of nitrogen losses from the surface soil.** Figure 23 and the accompanying table indicate total monthly and seasonal NO_3 losses from the experimental locations in Chilindamaji Watershed. Clearly, NO_3 losses in the maize field and erosion-control plots are roughly equal, demonstrating that soil loss itself does not account for the observed NO_3 concentrations, i.e., NO_3 loss in sediment is less than NO_3 loss due to infiltration. Again, note that organic forms of nitrogen, which may be present with washed-off fertilizers, are unmeasured and may be significantly high.

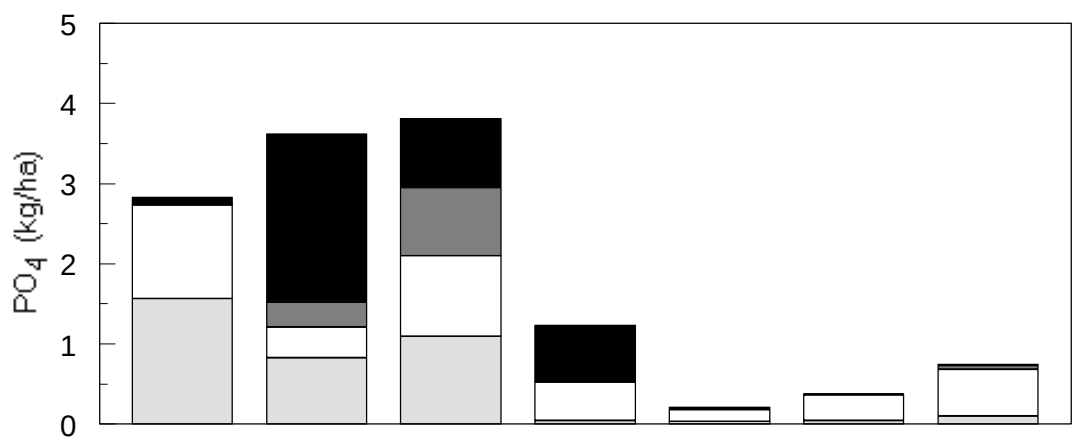


	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	0.009	0.003	0.011	0.002	0.001	0.000	0.001
Feb	0.002	0.004	0.021	0.018	0.005	0.007	0.058
March	0.002	0.000	0.028	0.005	0.001	0.000	0.002
April	0.002	0.024	0.007	0.017	0.000	0.000	0.000
Total	0.015	0.031	0.067	0.042	0.007	0.007	0.061

Figure 23. Monthly and seasonal NO_3 losses from field and erosion-control plots in Chilindamaji Watershed.

4.2.2.4. Orthophosphate (PO_4)

As does NO_3, PO_4 originates from a complex phosphorous cycle that involves both the decomposition of plants and the application of fertilizers. The similarity ends here, since PO_4 has a high desorption rate by soil particles. Much higher magnitudes of PO_4 are therefore present in surface waters. PO_4 is a primary cause of eutrophification, one of the major problems facing surface water bodies. Figure 24 and the accompanying table indicate total monthly and seasonal PO_4 losses from the experimental locations in Chilindamaji Watershed. The figure indicates that higher rates of PO_4 losses may be expected from maize fields than from tobacco or fallow fields, regardless of whether traditional or soil-conserving practices are used. These higher rates can be attributed to higher sediment yields (see Section 4.2.2.6) as well as to different cultural practices and fertilizer-management regimes.



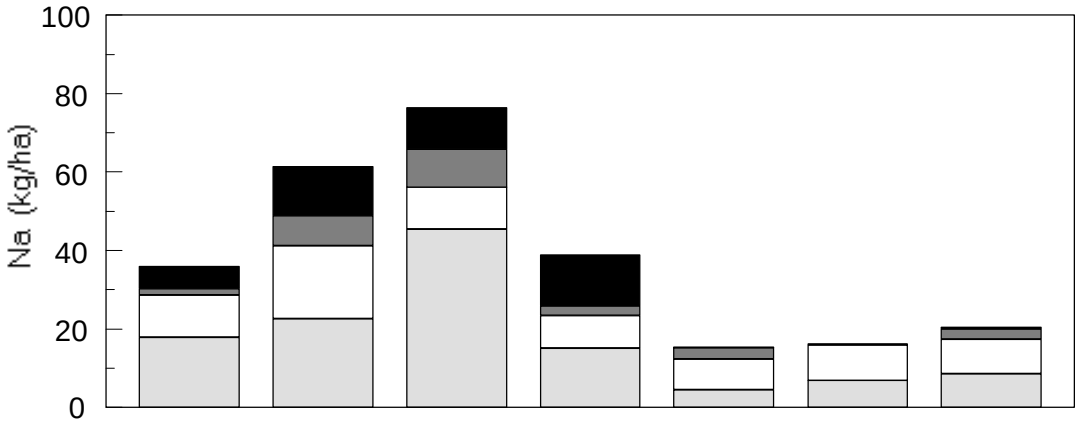
	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	1.567	0.824	1.093	0.046	0.032	0.047	0.100
Feb	1.169	0.393	1.009	0.483	0.149	0.318	0.582
March	0.004	0.308	0.854	0.005	0.013	0.000	0.050
April	0.090	2.104	0.859	0.699	0.015	0.014	0.011
Total	2.830	3.629	3.815	1.233	0.209	0.379	0.743

Figure 24. Monthly and seasonal PO_4 losses from field and erosion-control plots in Chilindamaji Watershed.

4.2.2.5. Other dissolved salts: Sodium (Na) and Potassium (K)

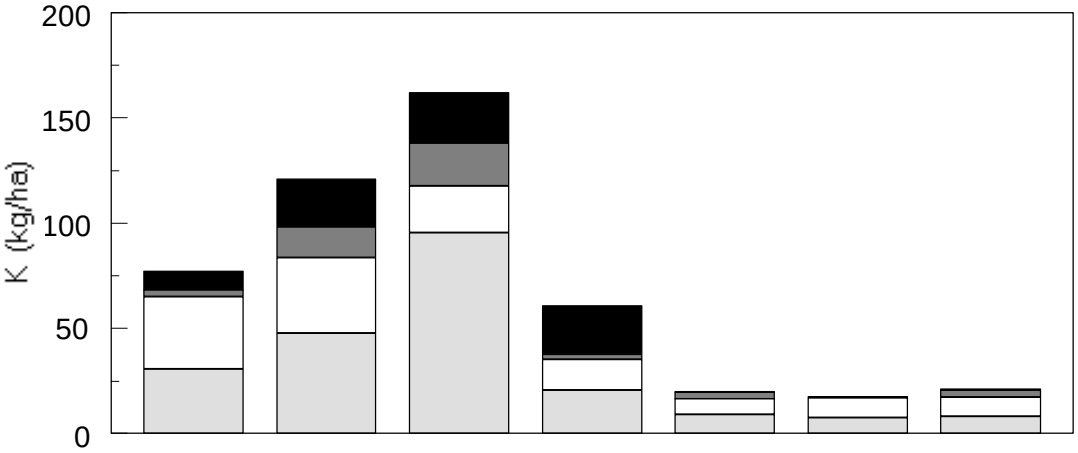
Both Na and K occur naturally in minerals and clay particles. While relatively high Na concentrations in surface water usually has minimal adverse impacts on aquatic habitats and humans, high concentrations of K is lethal to several species of freshwater fish and, in potable water, can damage human health. High concentrations of K can be found in nutrient-enriched waters and in eutrophic water bodies.

K is an essential element for proper crop growth, and in some cases K-deficient soils are augmented by fertilizers. Figures 25 and 26 and the accompanying tables demonstrate the effects of crop type and management practices on the presence of Na and K in surface water. For both elements, maize farming produced higher losses than from fallow fields or from tobacco farming.



	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	17.968	22.656	45.596	15.165	4.680	7.000	8.668
Feb	10.780	18.738	10.618	8.371	7.790	9.015	8.890
March	1.679	7.596	9.767	2.524	2.860	0.000	2.550
April	5.642	12.580	10.583	12.958	0.280	0.420	0.400
Total	36.069	61.570	76.564	39.018	15.610	16.435	20.508

Figure 25. Monthly and seasonal Na losses from field and erosion-control plots in Chilindamaji Watershed.

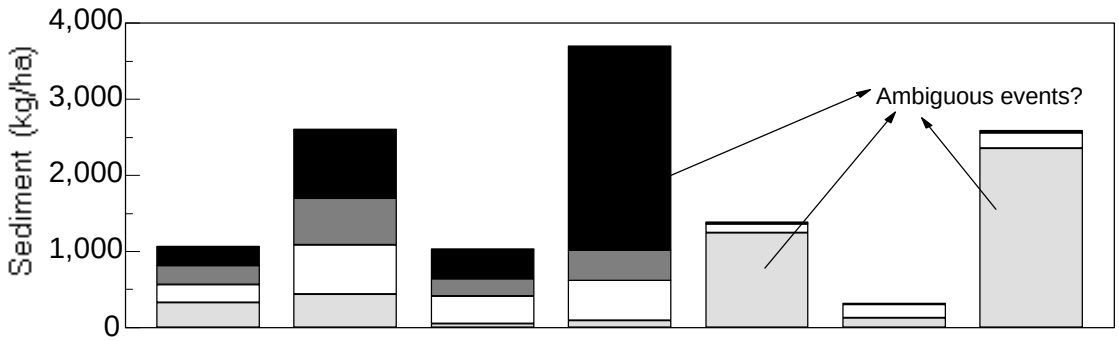


	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	30.729	47.725	95.597	20.655	9.180	7.680	8.202
Feb	34.404	36.000	21.994	14.555	7.455	9.360	9.346
March	3.241	14.629	20.700	2.692	3.200	0.000	3.240
April	9.028	22.863	23.863	23.095	0.320	0.660	0.600
Total	77.402	121.217	162.154	60.997	20.155	17.700	21.388

Figure 26. Monthly and seasonal K losses from field and erosion-control plots in Chilindamaji Watershed.

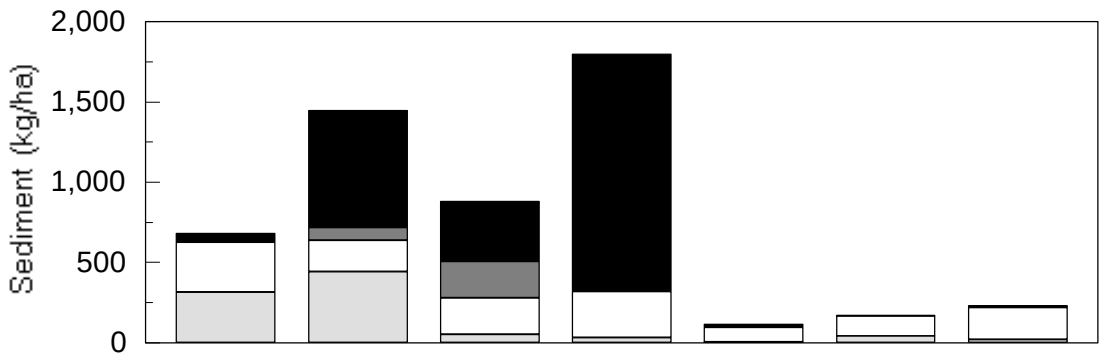
4.2.2.6. Soil loss (Sed.)

Excluded events (Section 4.2.1) lead to a large underestimation of the total seasonal sediment yield from the microcatchments. Numerical values of sediment yield based on the filtered sample cannot be used, therefore, to indicate the absolute magnitude of soil losses. Values of sediment loss can be used only in a relative context, i.e., for comparing farming methods and crops under similar conditions. To illustrate the loss of information due to sample filtering, we calculated monthly and seasonal sediment losses based on (a) the partial elimination method, in which events were discarded only with respect to the plot(s) affected (Figure 27), and (b) the completely filtered sample, in which an excluded event for any one plot resulted in discarding that event for all plots (Figure 28).



	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	335.900	443.791	52.528	98.606	1,249.200	128.700	2,361.152
Feb	232.800	644.117	362.356	526.387	114.736	179.375	204.000
March	247.700	615.543	227.664	391.328	7.328	0.000	2.022
April	253.190	902.000	396.000	2,689.930	22.904	15.888	25.526
Total	1,069.590	2,605.451	1,038.548	3,706.251	1,394.168	323.963	2,592.700

Figure 27. Sediment yields based on the partial elimination method. Note the large values of soil loss during the month of January (the month of ridge construction) from the erosion-control plots. Excessive soil loss may occur from unfinished ridges, yet will not be reported as ridge failure or damage.



	Pit 1(Burley)	Pit 2(Maize)	Pit 3(Maize)	Pit 4(Burley)	Burley Plot	Fallow Plot	Maize Plot
Jan	317.708	443.791	52.429	32.350	7.200	43.300	19.152
Feb	312.240	196.819	229.023	286.941	90.960	123.000	202.220
March	5.151	80.200	227.664	9.356	7.328	0.000	2.022
April	48.073	726.564	374.748	1,471.934	12.720	5.016	7.500
Total	683.172	1,447.374	883.864	1,800.581	118.208	171.316	230.894

Figure 28. Sediment yields based on the filtered sample. Note that under normal conditions (i.e., severe storms causing ridge damage on at least one plot were discarded), erosion-control plots have much lower soil losses than do plots cultivated under traditional agricultural methods. Furthermore, notice the substantial amount of soil loss observed from pit 4 during April.

In comparing Figures 27 and 28, it is clear that the filtered sample (Figure 28), although necessary for reliable intercomparisons, represents a gross underestimation of the total seasonal sediment yield. Large rainfall events can cause ridge damage and excessive surface erosion on one plot, simultaneously affecting other plots but less destructively. In fact, these events are the most crucial in understanding the field response to rainfall. The impact of these events is clear from Figure 27. If judgment is to be made based on the filtered sample (Figure 28), the wrong conclusion may be drawn, i.e., "Although erosion-control plots have reduced the erosion rates, erosion was not that significant of a problem to start with." Figure 27 demonstrates that such a statement does not reflect reality.

5. A Simple Method for Multiple-Objective Evaluation (MOE)

Sustainable agricultural development requires regulating the impacts of agricultural activities on several variables. For example, it is in the interest of the farmer to maximize crop yields while minimizing soil and fertilizer losses due to erosion. Concurrently, it is in the interest of society as a whole to eradicate or minimize the presence of harmful chemicals in surface waters. Considering these sometimes competing interests in a MOE is a complex task, one that requires input from social and physical scientists who are experts in anthropology, agronomy, climatology and hydrology, economics, and other disciplines. To add to its inherent complexity, MOE involves consideration of variables that do not necessarily share common units and do not reflect similar processes. For example, when determining an aggregate measure of performance, soil loss cannot be added to nitrate loss, regardless of the fact that both have units of kg/ha.

There are many approaches for evaluating management alternatives when faced with competing decision variables. Decision variables are those factors or effects in a MOE that must be maximized (e.g., farm profits) or minimized (e.g., soil losses). One approach is that of the USDA, which has developed a multiple-objective decision-support system for farm water-quality management (WQDSS; Yakowitz et al, 1993, Imam, 1994). WQDSS uses simulation and decision models to rank different farm-management systems based on their impacts on water quality as well as their effects on farm profitability. However, WQDSS requires much data in order to parameterize its simulation modules, and it also requires users to be familiar with decision theory. For MEMP's current needs, therefore, we advocate and propose a simple approach to MOE. We caution, however, that while this simple MOE can be used diagnostically, it should not be used as a stand-alone decisionmaking tool.

Most MOE methods are based on transforming the assembly of variables into common indicators, scores, or ranks that can be summed to obtain an aggregate measure of performance associated with competing alternatives. These aggregate measures are then compared against each other to determine the alternative that appears to satisfy most of the policy issues. Our proposed MOE framework is based on minimizing a summed value of ranks. For each decision variable (soil loss, nitrate loss, profit, crop yield, etc.), we assign a rank to each alternative (i.e., crop type and farm-management system) based on its relative performance against all other alternatives. If a decision variable is to be minimized, alternatives are ranked by integer values that *increase* as the decision variable associated with the alternative increases. Conversely, if a decision variable is to be maximized, alternatives are ranked by integer values that *decrease* as the decision variable associated with the alternative increases. For example, consider the seven plots in Chilindamaji Watershed. The seasonal totals of all seven water-quality indicators (the decision variables TDS, SO_4, NO_3, PO_4, Na, K, Sed.), must be minimized. (Conversely, if crop yield or sales profit data were available, then these would be maximized.) Table 16 illustrates this approach for the Chilindamaji case study, and is to be read as follows:

Step 1 For each row (rows are the decision variables), identify the alternative that has the lowest (if minimized) or the highest (if maximized) value. Assign a rank of **1** to this alternative in the row.

Step 2 Repeat the process in the same row; find the alternative associated with the next lowest (or highest) value, assign the rank **2**. Repeat the process until all ranks are assigned within the row.

Step 3 Repeat Steps 1 and 2 for each row (i.e., for each decision variable).

Step 4 Once all alternatives for each decision variable are assigned ranks, sum all ranks in each column.

Step 5 The alternative that has the lowest sum of ranks is the “best” alternative.

Note: If two alternatives have the same value for a decision variable, use subjectivity to determine which gets the lower rank. Use similar subjectivity in case of a tie in the sum of ranks.

Table 16. Demonstration of a Simple MOE for the Chilindamaji Watershed

Direction of assigning a rank to each alternative with respect to each decision variable:

Rule 1: If maximizing the variable, the alternative with the highest value is assigned the lowest rank.

Rule 2: If minimizing the variable, the alternative with the lowest value is assigned the lowest rank.

Decision Variable	Direction	Alternatives													
		Pit 1 (Burley)		Pit 2 (Maize)		Pit 3 (Maize)		Pit 4 (Burley)		Plot 1 (Burley)		Plot 2 (Fallow)		Plot 3 (Maize)	
		Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
TDS	Minimize	224.48	7	132	5	200.46	6	64.64	4	26.59	1	27.38	2	46.92	3
SO_4	Minimize	30.00	6	10.74	4	49.34	7	11.05	5	2.05	1	3.16	3	2.05	2
NO_3	Minimize	0.02	3	0.03	4	0.07	7	0.04	5	0.01	1	0.01	2	0.06	6
PO_4	Minimize	2.83	5	3.63	6	3.82	7	1.23	4	0.21	1	0.38	2	0.74	3
Na	Minimize	36.07	4	61.57	6	76.56	7	39.02	5	15.61	1	16.44	2	20.51	3
K	Minimize	77.40	5	121.22	6	162.15	7	61	4	20.16	2	17.7	1	21.39	3
Sed.	Minimize	683.17	4	1447.37	6	883.86	5	1800.58	7	118.21	1	171.32	2	230.89	3
Sum of ranks from each column			34		37		46		34		8		14		23
FINAL RANK			4		6		7		5		1		2		3

6. Recommendations

Monitoring activities that are designed to identify causes and effects of specific environmental problems differ from programs designed to inventory environmental resources. Building a successful environmental and water-quality monitoring program requires a clear vision of the environmental problem being addressed, a set of clearly stated and defined goals and objectives for the monitoring activities, and a well-defined criterion that can be used to judge whether these objectives have been achieved. Additionally, monitoring programs that are designed for the purpose of identifying parameters required in simulation studies are usually problem-focused, site-specific, and model-dependent. In the final analysis, these issues must be considered when designing monitoring and sampling schemes.

The concept of "representativeness" is an important aspect of water-quality monitoring. Statistical or analytical inferences concerning the impact of human activities on water quality may be confounded by the effects of topography, soil, and other factors. This is the fundamental reason for collecting data from several locations. In fact, the larger the number of variables (i.e., soil, topography, slope, etc.), the larger the number of sample sites required in order to adequately analyze and categorize the impact of these variables.

"Scaling" is another important aspect of water-quality monitoring. Scale effects must be considered when determining the representativeness of sampling locations. For example, consider soil-loss data collected from a small microcatchment with uniform slope. Although the microcatchment may be representative of the dominant soil and crop management regimes at larger scales, it may not reflect the effects of large-scale topographic control of soil erosion. Intervening processes (such as deposition) govern sediment transport from the watershed at these larger scales.

Ensuring the usefulness of data is extremely important. Monitoring agencies must guard against problems that can affect the reliability of the collected record. Data quality control can be attained through the following guidelines:

1. **Consistency:** Consistent methods must be used when collecting samples. Factors that are considered constant for the duration of the experiment should remain constant throughout. One example is the contributing area of a microcatchment. If such factors cannot be held constant, their variability must be monitored and reported.

2. **Replicability:** When collecting water-quality samples, more than one sample must be sent to the laboratory. The collection of more than one sample, especially when these samples are separated in time, provides a guard against errors and random noise that can contaminate a single sample.

3. **Timely reporting:** This is extremely important when sample collection is performed by individuals other than those performing or documenting the analysis. Reporting analytical results promptly will (a) enable the tracking of problems as they occur, and (b) provide an opportunity to assure the integrity of the data samples.

4. **Reliability:** Predetermined guidelines can be established to determine whether the numerical values reported correspond with the physical and conceptual notions underlying the experiment. For example, runoff values must be less than rainfall when baseflow is not expected to contribute to the collected runoff. Reliability guidelines must be simple and easy to perform so that MEMP staff can perform these checks easily and unequivocally.

5. **Documentation accuracy:** Raw data, procedures, and results must be documented fully and accurately. A knowledgeable supervisor must critically read the staff's reports; he or she must check for and correct any lapses or errors.

Our assessment of MEMP's first year of activities in Chilindamaji indicates that the program satisfies several components of a successful monitoring program. However, there are some aspects of the program that can be substantially improved with minimal or no costs, but which do require some effort on the part of MEMP staff, collaborating local farmers, and MEMP's outside experts. In Section 6.1 to 6.3, we offer several recommendations, separated into three subcategories: Recommendations regarding experimental infrastructure, recommendations regarding data reporting and documentation, and future directions.

6.1. Recommendations Regarding Experimental Infrastructure

The following recommendations will result in a substantial improvement in the reliability and accuracy of the collected rainfall-runoff data.

6.1.1. Runoff Collection Pits

Actions must be taken during future data-collection seasons to ensure that water collected in each pit represents the surface runoff. Errors due to direct rainfall and the inclusion of baseflow must be minimized by covering the pits and securing the impermeability of their lining. Pit covers can be designed to allow for runoff measurements and water-quality sampling while being immune to damage or theft. The installation of handpumps will facilitate the cleaning and preparation of pits for future rain events.

6.1.2. Contributing Area

Under ideal conditions, the contributing area of each microcatchment must remain constant during the experiment through the use of boundaries impermeable to damage by extreme events. This is harder to attain in the field than in theory, and consequently evaluations of the total contributing area must be made when ridges fail. Subsets of contributing areas can be predetermined, the smallest of which represents the microcatchment itself. Larger areas include the microcatchment and, progressively, the areas beyond the ridges. Whenever a ridge failure occurs, the contributing area associated with this event can then immediately be adjusted to reflect the larger microcatchment. If the damaged ridges subsequently remain unrepaired, the larger area must become the contributing area to the pit from that point on. Farmers should therefore be encouraged to maintain ridges on their fields in good condition for their own well-being as well as for areal consistency throughout the experiment.

6.1.3. Raingages

Under ideal conditions, each microcatchment must be equipped with its own raingage. It is not essential to install a sophisticated raingage. Standard, nonrecording, simple, yet inexpensive cumulative precipitation gages can be installed at the manufacturer's recommended height above or adjacent to the collection pit. Individual raingages for each pit are preferable because most large rainfall events are characterized by the significant spatial variability common to monsoon-type tropical storms. The distances between the field microcatchments are large enough to justify individual raingages.

6.1.4. Rainfall Intensity

The amount of soil loss during a single rainfall event correlates more strongly with the maximum intensity of the storm than with total rainfall. By providing rainfall intensity data, a better understanding of the rainfall-erosion relationship for each of the sampling locations can be ascertained. So as to achieve this purpose, it is preferable to have an intensity record at each pit. However, the cost associated with installing, maintaining, and operating additional recording raingages may be prohibitive.

6.2. Recommendations Regarding Data, Reporting, and Documentation

6.2.1. Nutrient Application Data

Knowledge of the timing of nutrient applications is not sufficient to describe a farm-management regime, nor is it sufficient to evaluate the impact of the regime on water quality. Documentation of the amount and type of applied fertilizer, as well as the method of application, is also necessary.

6.2.2. Full Reporting of Rainfall Events

Although rainfall events that do not produce runoff cannot be used to determine the hydrologic response of catchments, knowledge of these events is helpful in identifying the overall hydrologic characteristics of the watershed. Furthermore, as an integral part of the water-quality data and from a statistical perspective, it is important to report these events.

6.2.3. Soils Data

Soil texture classifications were made for some sediment samples in January, 1995. Although soil texture is useful in understanding the sedimentation process, it must be complemented by particle-size distribution data from the soil on the field. Ideally, primary particle-size distributions (i.e., percents of sand, silt, and clay) should be determined at several depths along a full root zone profile for each crop. These data will aid in determining the water-retention properties of the soils.

6.2.4. Promptness, Initial Analysis, and Feedback

As discussed above, prompt collection and reporting of rainfall-runoff events will allow MEMP staff to perform initial data assessments. If errors are found to exist, a feedback communication must be initiated, and the conditions associated with the error must be noted and rectified if possible.

6.3. Future Directions

It must recognized that because of external controlling and influencing factors (climate variability and farm prices being an example of each), environmental monitoring and impact assessment programs designed to provide recommendations to policymakers must be both comprehensive and long-term. It is counterproductive to terminate such programs after one or two data-collection seasons. From a scientific perspective, such a short duration does not provide a statistically robust record. Conversely, a record that is statistically significant provides much greater confidence in the results, clearly an important objective when the results are meant to be used as policy guidelines. A commonly shared objective of any environmental monitoring program is the reduction of uncertainties associated with decisionmaking. This can only be achieved by monitoring land and water-quality responses under a variety of conditions, especially those that occur as a result of the normal interannual variability of climate.

Agricultural models such as the USLE can be used to predict the impact of farm operations on water quality. However, these predictive tools require fitting to local conditions (refer to Section 2.2.3 and the nonrepresentativeness of Table 11 to conditions in Malawi). A longer record will permit scientists to calibrate models such as the USLE for both normal and extreme climate conditions in Malawi.

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