IRINGA SOIL AND WATER CONSERVATION PROJECT
IRINGA DISTRICT, TANZANIA
HIMA(IRINGA)/DANIDA

# WATER RESOURCES MONITORING ANNUAL REPORT

## April 1993 - October 1994

# DRAFT

Jens Kristian Lørup

Institute of Hydrodynamics and Hydraulic Engineering
Building 115
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2800 Lyngby
Denmark

FEBRUARY 1995

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# FOREWORD

This annual report contains data and preliminary results of the first 1½ years of the water resources monitoring activities that were started nearly two years ago within the HIMA/Iringa project.

More than three years have gone since the first concrete steps were taken to establish a Water Resources Monitoring component within the HIMA/Iringa project. It may seem like a long time from the initial start until the first preliminary results are presented. For those having been involved in the long process of initial discussions, planning of activities, procurement and installation of equipment, and - most important of course - the daily routine data collection, it is however hard to imagine how things could have been done more speedily.

It would have been impossible to get that far if the cooperation between the involved parties had been less than optimal. The efficiency and helpfulness of the HIMA-management, all the way through, is very much acknowledged. Similarly, the actual high quality of data collection has only been achieved through the dedicated and hard work of the Iringa Regional Hydrologists Office, in the field as well as in the office. The instrumental role of the Technical Advisory Services Division of DANIDA Headquarters, Copenhagen in supporting and facilitating the cooperative monitoring activities is also very much acknowledged.

Lyngby in February 1995

Eggert Hansen
Professor of Hydrology

Institute of Hydrodynamics and Hydraulic Engineering
Technical University of Denmark

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## EXECUTIVE SUMMARY

A Water Resources Monitoring component was added to HIMA (Iringa) in 1992. The monitoring was started in mid-late March 1993 after the establishment of gauging stations and the installation of instruments.

The report covers the period from April 1, 1993 until October 31, 1994. In Tanzania the "water year" as used by the hydrologists runs from November 1 to October 31. Thus the reported period includes *the 1993/94 water year which runs from November 1, 1993 to October 31, 1994.*

The major findings from this period will shortly be summarized below and discussed in relation to the two main objectives of the monitoring namely: 1) to monitor the impact of the project's afforestation and soil and water conservation activities on the water resources in the project area, 2) to develop a better understanding of the impact on the water resources of different types of land use and management practice in the project area.

The monitoring is carried out in 4 smaller catchments of about 5 km$^2$ in Kilolo Division, 50-80 km south of Iringa. The catchments include a forested (evergreen) catchment, Mgera; a cultivated catchment partly outside the present HIMA priority area, Gendavaki; and two catchments within the present HIMA priority area, Muhu and Ihaka. Approximately 85% of Mgera is covered with forest, while 65-75% is cultivated in Gendavaki, Muhu and Ihaka and the rest include grassland, bush, woodland, and forest/plantations. Rainfall and discharge are measured continuously, and soil moisture is measured monthly in Mgera, Gendavaki and Muhu, whereas only rainfall and discharge at the end of the dry season are measured in Ihaka. Thus most of the findings presented below are based on the results from the three former catchments. Climatic parameters have been measured at a weather station placed in the Muhu catchment. Water quality analyses, including physical, chemical, and microbiological parameters, have been carried out each month or every second month.

Based on the results from the first 1½ years of the monitoring some preliminary conclusions are arrived at. A few proposal for the use of hydrological monitoring in other HIMA-activities outside the present monitoring area are given as well.

### Water quantity

<u>Quality and collection of data</u>

Generally the collection of data has proceeded as planned and the quality of the data is in general very satisfactory.

The weekly collection of data undertaken by the hydrology technician and the daily rainfall readings undertaken by the local farmers have been carried out regularly during the whole period. With a few exceptions all the planned data have been collected. The few missing data have been due to technical problems and discharge data from Muhu for one month were stolen. The technicians have been able

to make the necessary adjustments and repair of instruments. Daily rainfall and runoff data for each of the monitored catchments exist for the whole monitoring period, and the missing data have not impeded the planned analyses. Relatively few discharge measurements exist for high water levels. Thus, the discharge during heavy rainfall events are not very precise, especially for Muhu and Gendavaki.

The raw data as well as the data analyzed by the hydrological office have been checked, and the quality is in general very good. However, it has been necessary to change the local observer at one of the rainfall stations, and it has been necessary to improve the reading from the evaporation pan.

The data material makes more analyses possible than presented here, e.g. detailed analysis of climatic data, rainfall intensities, infiltration conditions (from soil moisture measurements), etc, which can be carried out by the hydrological office according to need.

Catchments characteristics

As one of the aims of the monitoring is to compare the effect on the water resources of different types of land use and agricultural practices, it is important that the selected catchments, except for the land use, are similar in terms of physiography, i.e. size, shape, slope gradient, altitude, geology, rainfall, etc. Achieving that, the differences in hydrological response between the different catchments can be ascribed to the differences in land use only. In this respect 3 catchments which are very similar in terms of topography, altitude, and size and shape of the catchments have been selected. Furthermore, the rainfall patterns and amounts - at least for the first water year - are very similar as well (see Table 1). These facts are highly facilitating the possibility to link the differences in hydrological response in the catchments with differences in land use practised in the respective catchments.

**Table 1** - *Comparison between some physiographic features in Mgera (forested), Gendavaki (cultivated) and Muhu (cultivated) catchments.*

| | MGERA | GENDAVAKI | MUHU |
|---|---|---|---|
| Yearly rainfall (mm) (1993/94) | 1257 | 1231 | 1128 |
| Altitude range (m) | 1890-2030 | 1895-2045 | 1850-2030 |
| Catchment size ($km^2$) | 5.15 | 5.13 | 5.14 |
| Average slope gradients (%) | 20-30 | 20-30 | 20-30 |

The impact of the different types of land use on the water resources

As mentioned above the rainfall is very similar in the monitored catchments namely 1257 (Mgera), 1231 mm (Gendavaki), 1128 (Muhu) and 1136 mm (Ihaka). According to historical records (1974-80) the yearly average rainfall in Muhu is 1352 mm. Thus, the rainfall for the 1993/94 water year is lower than average but can not be considered a dry year. However, the rainy season started late. Apart from 3 days with heavy rainfall in December the continuous rain did not start until the beginning of January.

The monthly average temperature for 1994 varies from 11.6 in August to 16.9 in January. The temperature are similar for the recorded period in 1993. The lowest recorded temperature in 1994 is 5.6 °C in June and the highest is 25.7 °C recorded in November.

The collected data for rainfall, runoff, and soil moisture make it possible, for each of the three catchments, to establish a yearly water balance for the 1993/94 water year and low flow values for the dry seasons in 1993 and 1994, which are presented in Table 2.

In general, the two cultivated catchments, Muhu and Gendavaki, are very similar in terms of hydrological response, whereas the forested catchment, Mgera, is quite different from the two cultivated catchments.

The ***yearly runoffs*** (the amount of water passing the outlet of the catchments yearly) for the 1993/94 water year from Gendavaki and Muhu are almost equal, i.e. 397 mm and 393 mm, respectively. Although Mgera has received the highest total yearly amount of rainfall, the yearly runoff from this catchment is 105 mm (or 27%) lower than from the cultivated catchments. Thus the runoff coefficient (the yearly runoff as the percentage of the yearly rainfall) is 32% and 35% for Gendavaki and Muhu, while only 25% for Mgera. The actual evaporation from Mgera is considerably higher, namely 960 mm as compared to 804 mm and 717 mm for Gendavaki and Muhu, respectively. The differences in soil moisture storages as well as in the groundwater storages from the start of the water year to the end are estimated to be low as seen from Table 2.

**Table 2** - *Yearly water balance in mm for the 1993/94 water year (1.11.93 to 31.10.94) and specific low flows for the 1993 and 1994 dry seasons for Mgera, Gendavaki, and Muhu catchments.*

| | MGERA | GENDAVAKI | MUHU |
|---|---|---|---|
| **Water balance components:** | | | |
| Rainfall (P) | 1257 | 1231 | 1128 |
| Runoff (Q) | 290 | 397 | 393 |
| Change in soil moisture storage | - 3 | + 4 | + 11 |
| Change in ground water storage | + 10 | + 27 | + 10 |
| Actual evaporation, $E_a$ | 960 | 804 | 717 |
| **Specific low flow:** | | | |
| Specific low flow 1993 (l/s/km$^2$) | 2.0 | 6.7 | 8.0 |
| Specific low flow 1994 (l/s/km$^2$) | 3.3 | 7.5 | 8.6 |

It might have been expected that the higher yearly runoff from Muhu and Gendavaki could be ascribed to higher direct surface runoff during heavy rains caused by cultivation on the steep slopes. However, a more detailed analysis of the runoff pattern shows that the ***wet season runoff*** (December to May)

The percentage of the catchments covered by valley bottoms, either natural swamps or area used for vinyungu cultivation, may also play a role regarding the hydrological response and in particular on the actual evapotranspiration. As these areas often are water-logged during the rainy season and water logged or having a high soil moisture content during the dry season, a relatively higher evapotranspiration will take place from such areas compared to the hillslope areas. The fact that the higher rainfall in Gendavaki compared to Muhu results in a higher actual evapotranspiration rather than a higher runoff may be due to differences in the portion of the catchments covered by valley bottom/wetland. Thus, when making a detailed land use survey in each of the catchments, the portion of the catchments covered by valley bottom/wetland should be specially marked out.

The cultivated catchments are similar regarding total yearly runoff and specific low flow, whereas large differences exist between the forested catchment and the cultivated catchments for these characteristics. With regard to runoff during the wet season in general and peak flows during days with heavy rainfall events all three catchments are quite similar as seen from figures 4.15, 4.17 and 4.19. The ***direct runoff*** (here defined as that part of the rainfall which leaves the catchment as runoff during or within 24 hours after the rainfall event) makes up a small percentage of the rainfall for all the catchments even during days with high total rainfall amount and/or high rainfall intensity. For instance, although the average slope gradient (except the valley bottoms) for all the catchments varies between 20-30% and the 1993/94 water year include daily rainfall amounts of 40-50 mm (and a single day with 85 mm at Gendavaki) and a few 30-min rains of 25-30 mm, the maximum daily runoff during the whole water year, even for the cultivated catchments, was only 4.8 mm - including baseflow.

It is known from a number of places in Africa that the major part of the total yearly soil erosion often happens during few but very heavy rainfall events. Thus the rainfall event at Muhu with the highest recorded 30-min rainfall intensity was analyzed. The total rainfall was 46.6 mm within 3 hours and the highest 30-min rainfall was as high as 28.6 mm. However, although this resulted in a considerable increase in the streamflow, the runoff never exceeded 0.4 mm/hr and less than 2 mm out of the 46.6 mm rainfall, i.e. about 4%, left the catchment as runoff within the succeeding 24 hour after the start of the rainfall event. An analysis of a heavy rainfall event in Mgera, with a max. 30-min rainfall of 21.2 mm, showed similar results.

A major part (probably more than 50% in most cases) of the runoff measured at the outlet of the catchment originates from the riparian area and the valley bottoms/wetland in general, where little rainfall can infiltrate due to the high groundwater table or waterlogged soils. The highest daily runoff during the rainy season was unexpectedly recorded at Mgera, and it is believed that most of this comes from rainfall in the riparian areas and not from the forest-covered hillslopes. *Thus, although the highest daily runoff is found at Mgera, it is still likely that the highest daily surface runoff is found in one of the cultivated catchments.* It should also be emphasized that the peak flows still are subject to some uncertainties due to relatively few discharge measurements for high water levels. Thus, when more discharge measurements exist for high water levels, some adjustment of the peak flows may be needed.

Thus, during the day in the 1993/94 water year with the highest recorded 30-min rainfall (28.6 mm) it might be only about 1-2% of the rainfall from the hillslopes that reach the streams through ***surface runoff***.

To recapitulate, a few preliminary conclusions can be drawn when comparing the hydrological response from the three catchments from the first 1½ years of the Water Resources Monitoring:

1) The *total annual runoff* from the forested catchment is considerably lower than from the cultivated catchments, mainly due to a higher evapotranspiration from the forested catchment

2) The *accumulated dry season runoff* and in particular the *specific low flow* is much lower from the forested catchment than from the cultivated catchments.

3) The cultivated catchments and the forested catchment show similar hydrological response in terms of *wet season runoff* and *peak flows* as measured at the outlet of the catchments

This indicates that not only eucalyptus and other fast growing tree species, but also natural evergreen forests may *consume* water rather than *conserve* water at least in areas with relatively stable and porous soils that can resist raindrop splash and maintain a high infiltration capacity without a forest cover.

It should be emphasized that these are preliminary conclusions. However, they are food for thought as they differ from the view often met in discussion with HIMA staff and officers at district and regional level.

On the other hand, these indications agree very much with a former study at Mbeya from 1958-1969. The replacement of an evergreen forest by smallholder cultivation in an area with very steep slopes (about 30°) resulted in a large increase in yearly runoff. There was only a marginal increase in recorded surface runoff and sediment yield, whereas the dry season flow was doubled. The low increase in surface runoff and sediment yield was believed to be due to the remarkably stable, porous nature of the ash-derived soils typical in the area (Edwards & Blackie, 1981).

The impact of afforestation and soil and water conservation activities on the water resources in the project area

As the monitoring only has been carried out for 1½ year and as relatively few project activities have been implemented in the monitored catchments yet, it is too early to conclude on the effects of the project activities on the water resources. However, as outlined in the preceding section, the monitoring has provided some information about the hydrological response including infiltration conditions, the extent of surface runoff, and the availability of water in the streams. A few additional comments will be given below.

As mentioned in the preceding section the percentage of the rainfall on the hillslopes that reaches the stream via surface runoff is surprisingly small, i.e. 1-2% even during rainfall events with a very high rainfall intensity.

However, it should be pointed out that this is average values for the whole catchment. Thus in the more sensitive parts of the catchments, i.e. the steepest slopes and areas where the infiltration conditions are poor and/or the rain are easily directed to the streams, a much larger percentage of surface runoff may occur.

In this case special attention should be given to roads, footpaths, and residential areas. Based on observations in Muhu during the rainy season it is believed that a major part of the surface runoff and consequently the soil erosion in the catchment is taking place in connection with foot path, roads and residential areas, which act as generators of surface runoff (due to low infiltration) and/or conveyors of surface runoff from other roads/footpaths, roofs of houses and areas around the houses where little infiltration takes place. The gully along the footpath from Chalinze (one of the sub-villages in Bomalang'ombe) and down to the bridge at Muhu stream, that has developed within the last 2-4 years, is an excellent example of the combination of an area with little infiltration (resulting in considerable surface runoff) and a footpath acting as an medium for the transport of water - directly to the water course. However, rill erosion has also been observed in the steepest fields in Ihaka with slope gradients of approximately 100%.

It should also be noted that a certain part of the surface runoff at the upper part of the slopes may infiltrate further down the slope before reaching the stream. Therefore the direct runoff measured at the outlet of the catchment does not necessarily account for all the surface runoff taking place in the catchment.

As the implementation of soil and water conservation so far has be very limited, it is not believed that they have had any measurable effect yet. However, there are indications that the farmers now really start adopting soil and water conservation measures in both Muhu and Ihaka, especially the upper part of both catchments. Thus it is important that the implementation of conservation measures and the monitoring are coordinated.

The relatively low surface runoff that is observed is probably mainly due to the soils which, favoured with a relatively high organic matter content, have good physical properties, including high porosity and good aggregate stability, which makes them resistant to raindrop splash and ensures a high infiltration capacity. Measurements of the saturated hydraulic conductivity in Muhu with a double ring infiltrometer also indicate that the soils still have good infiltration conditions because values of $7 \cdot 10^{-5}$ m/s (= 277 mm/h) and $4.2 \cdot 10^{-6}$ m/s (= 15 mm/h) were measured for the topsoil and the subsoil, respectively. When the results of the forthcoming soil analysis in the catchments arrive, they will be an important contribution to our understanding of the processes taking place in the catchments.

The high specific low flow values for both Muhu and Ihaka also clearly demonstrate that infiltration conditions are good, and the low flow values also seem to be relatively high compared to the demand of water for domestic purposes in the area if the water at the outlet of the catchment is considered. From preliminary local information it may be estimated that no more than 2-3000 persons rely on water for domestic purposes from Muhu. With an estimated consumption of 25 l/day/capita this corresponds to a average demand of 1.15 l/s assuming that the water is collected between 6 am. and 6 pm. For comparison the lowest flow recorded at the gauging station is 41.33 l/s. However, most water is collected in the upper part of the catchment at a collection point that has an estimated catchment area of about 0.4 km$^2$. If the specific yield for this area is assumed to be as high (although it is more likely to be a bit lower) as for the whole catchment (5.14 km$^2$) this would correspond to a low flow of 3.21

domestic use. On the other hand it is not surprising that this is the location with the highest biological contamination, as this is the sampling point with the expected highest human and livestock activity. There are three farmers that graze their cattle in the sub-catchment upstream the point of sampling and there is a cattle watering point next to the stream that certainly is an obvious source for severe microbiological contamination. The high amounts of faecal coliform correspond very well with the fact that diarrhoea is a serious problem in Bomalang'ombe, and that very few people boil their water. The second and third highest values are found at Ihaka and Muhu gauging stations respectively, whereas the faecal contamination measured at Mgera is considerably lower than at Muhu, possibly due to few human activities. However, the faecal coli content is far above the recommended level of 4 E.Coli counts/ 100 ml for all samples at all gauging station. It should be mentioned that even the water from many water supply schemes contains more than 4 E.Coli counts/100 ml.

The measured concentration of ***chemical pollutants*** has been very low in the water samples collected from the catchments until now - at least regarding the measured parameters. However, it should be mentioned that no analyses for the content of pesticides have been undertaken so far. As pesticides are commonly used, especially for growing of vegetables (e.g. tomatoes and cabbages) in the valley bottom, this may result in some pollution of the nearby water sources.

The content of nitrogen, in terms of ammonium and nitrate, is very low. The ***ammonium*** content is almost the same for the different catchments, whereas the ***nitrate*** content is highest at Gendavaki and lowest at Mgera. However, due to the low total nitrogen concentrations for all of the catchments, i.e. less than 0.3 mg N/l, these differences are not important in evaluation of the effect of the land use on the nitrogen content in the water. The low levels of ammonia and nitrate during the dry season (where the water almost solely originates from groundwater) indicate that small amounts of nitrogen are leached from the root zone in all of the monitored catchments. For instance, with a yearly runoff of 393 mm from Muhu the average contents of ammonium and nitrate at Muhu gauging station of 0.065 mg N/l and 0.14 mg N/l, respectively, correspond to a yearly leaching of 0.8 kg N/ha, which is very low. This indicates a soil with a low availability of nitrogen (and little use of fertilizers). For comparison it can be mentioned that it is not unusual to find nitrate concentrations of 10 mg N/l in the streams in Denmark and N-leaching losses of 20-50 kg N/ha - especially on sandy soils. It should again also be emphasized that most of the samples originate from the dry season and therefore do not give sufficient information on the possible nitrogen losses through surface runoff during periods with heavy rain, although the few measurements during days with relatively heavy rains do not indicate any considerable increase in the ammonium and nitrate concentration.

There is no problems with too high amounts of chloride or fluoride (as e.g. experienced in the northern part of Tanzania).

The average levels for ***turbidity*** (which provide information of the amount of suspended material in the water) are below the permissible values. The highest values are found at the gauging station in Muhu, and the values here are almost twice as high as the average value for all stations. This corresponds very well with the fact that a considerable sediment transport and sedimentation can be observed at this station the year round. Increased bank erosion, among other things as a result of vinyungu cultivation, could be a likely explanation for the relatively high turbidity at this collection point. On the other hand, the low values for turbidity and colour at the upper part of Muhu may be due to the fact that vinyungu cultivation almost have been abandoned in this part of the catchment. The low turbidity at Mgera, which is less than half of the average value from the other stations, may be a combination of a forest cover on the hillslopes and a swampy area immediately upstream the gauging station where low flow velocities possibly result in increased sedimentation.

The average level for colour is also approximately twice as high at Muhu gauging station as compared to the average of the other stations. It may be expected that the average values for especially these two parameters would have been higher if more samples had been collected during periods with heavy rains.

*In general it can be concluded that there is not as marked differences between the effects of the land use on the water quality as the differences between the effect of the land use on the water quantity.*

**Recommendations**

Implications of the preliminary results of the monitoring in relation to project activities

The conclusions which have been arrived at are based on the results from the first 1½ years of the Water Resources Monitoring and are still very preliminary and should be considered as such. Nevertheless, the monitoring has revealed that there are some marked differences between the hydrological response from the different catchments presently monitored.

The fact that not only the total yearly runoff but also the dry season flow and in particular the specific low flow are considerably lower at the forested catchment compared to the cultivated catchments indicates that the often common belief that trees conserve water rather than consume water often is not true, and therefore the issue should be reconsidered and discussed within the project.

This is not to state that it is not right to plant trees - not at all - as there are many good reasons to plant trees, not least in Kilolo Division, especially in the most infertile area where fuelwood and timber production are good alternatives to annual crop production for the farmers in the area.

However, if trees are planted with the aim of improving the amount of water in the streams, it should be carefully considered whether tree planting is the proper solution. Especially in cases where fast growing species are used it is most likely to result in decreased water availability. Also, it should be pointed out that e.g. plantations with a closed canopy often have less ground cover compared to many types of natural regeneration.

Regarding land use and water resources it would be advisable that catchments protection activities are planned according to the status/use of the catchments/sub-catchments. E.g. in Muhu the sub-catchment upstream the point where water for domestic use is collected covers about 0.4 $km^2$ of the 5.14 $km^2$ of Muhu upstream the gauging station. Thus in terms of water source protection this part of Muhu should be given higher priority than the remaining part of the catchment.

The result from the first 1½ years of the monitoring also showed that on average for the catchments a surprisingly small portion (1-2%) of the rainfall, even during the most intense rainstorm, reaches the stream as surface runoff. This shows that cultivation on steep slopes as in Muhu not necessarily results in very high rates of surface runoff in areas where the soils still favour a good infiltration. This could indicate that physical soil conservation measures can be restricted to those parts of the catchments most susceptible to soil erosion, e.g. the steepest slopes, in connection with footpaths and runoff from roads and residential areas. In the remaining part of the catchments biological measures favouring maintenance of organic matter content and soil nutrient status may be given highest priority. A high organic matter content will help maintaining a good soil structure (and thereby high infiltration and resistance to raindrop impact), and an improved soil nutrient status will, apart from its main purpose of giving the farmer a higher yield/income, give a better crop cover and thereby a better protection against raindrop impact and surface runoff.

However, it should be emphasized that these suggestions are based on preliminary results from the monitoring and meant as one out of many inputs for future planning. The farmers (and the project) may have other and more relevant reasons to select other strategies and activities.

Water quality analyses showed that the microbiological contamination of the water is the most serious problem regarding water quality. As diarrhoea also is reported to be severe in Bomalang'ombe, it is proposed to identify obvious sources of this pollution in order to reduce it. The cattle-watering point next to the water collection point is one obvious point of pollution. An improvement and protection of the collection point itself is also likely to improve the situation. However, it should be kept in mind that high coliform counts are a very common problem which the DANIDA Water Project also has faced in many of their schemes. Thus, with the DANIDA Water Project in Iringa having more than 10 years of experience on this issue, it is proposed that HIMA take up this issue with the water project. Regarding the possible health risk due to the use of pesticides it is proposed that analyses of pesticides are initiated as discussed below.

<u>Additional activities and adjustment of the activities within the presently monitored catchments</u>

As the data collection in general and the collection of data on water quantity in particular have been progressing well for a long time, no major changes in the monitoring programme in the four catchments presently monitored are proposed. Instead the proposals below reflect some additional activities which are felt necessary to benefit most from the data that are collected in the present monitoring programme:

1) Discharge measurements

It should be aimed at obtaining more discharge measurements during the rainy season in order to establish more precise rating curves (relation between water level and discharge) for high water levels.

2) Soil moisture measurements

It is proposed that soil moisture measurements are carried out each fortnight at the end of the rainy season/beginning of the dry season and at the end of the dry season/beginning of rainy season in order to get a better possibility to make a more detailed calculation of the actual evaporation during the dry season from the soil moisture data

3) Sediment measurements

Sediment measurements would be an important addition to the present monitoring programme in order to evaluate the extent of soil erosion from the monitored catchments. As the present monitoring activities now are proceeding smoothly both technically and logistically and the hydrology technicians have become familiar with the new techniques, it will be possible to include this in the monitoring activities. However, to make proper sediment measurements is difficult and also implies that a lot of time has to be spent in the field to sample. Therefore it should be planned in close cooperation between the hydrologists, the project, and the village government.

4) Water quality analyses

In order to get a better knowledge of the water quality during the rainy season it is proposed that water sampling and analyses are made weekly or every fortnight during the months with heavy rains, primarily January - April, but the analysis should then just include the parameters of major interest namely: turbidity, colour, ammonium and nitrate, and faecal contamination. However, all the parameters included in the programme presently should still be analyzed every second month.

Due to the possible health risk from the use of pesticides, not least in connection with vinyungu cultivation, and the ongoing debate and uncertainty related to this it is proposed that analyses of pesticides should be included in the water quality analyses. It is proposed that the agricultural unit makes a small survey of the type of pesticides (fungicides, insecticides and herbicides) that are used by the farmers and at what time of the year in order to find out which type of analyses should be carried out and which time of the year the sampling shall take place. The Government Chemist in Dar es Salaam has got a new laboratory in September 1994 and is now able to carry out analyses for a number of pesticides.

5) A detailed survey of the catchments.

To be able to make a proper link between the land use practised in the monitored catchments and its impact of the hydrological response that is monitored, a more detailed description of the catchments is needed. This includes a more precise estimate of the different types of land use represented in the catchments, the percentage of the various types of crops grown on the cultivated land, the species composition in the forest, and the characteristics of the trees regarding e.g. root depth and distribution, and the portion of the catchments covered with valley bottom/wetland. It is proposed that the activities mainly shall be carried out by HIMA-staff from the agriculture and forestry units and planned together with the TUD-consultant during his next visit to the project.

6) A soil survey in the monitored catchments.

This is almost as important as the land use survey. The following analyses with relation to the physical/hydrological behaviour of the catchment should be carried out:

a) Saturated hydraulic conductivity as determined with a double ring infiltrometer
b) Determination of porosity and bulk density
c) Soil moisture retention curves (including determination of field capacity and wilting point)
d) Particle size distribution
e) Organic matter content

Furthermore, this could be combined with a number of analyses of soil chemical parameters with more agronomic relevance if this is wanted by the project.

It is proposed that at least two sampling points should be selected in each catchment and that a double determination should be made for each parameter. The soil sampling should take place in connection with the TUD-consultants' next visit to the project, and the analysis should be carried out at Sokoine University of Agriculture, Morogoro.

The use of water resources monitoring outside the existing monitored catchments

1) Water quality analyses

The request from the project to include water quality analyses in areas outside the present monitored areas can highly be recommended. There exists a lot of statements and beliefs on the impact of various activities on the water quality but very little knowledge. Water quality analysis is an important tool to define the extent of the problems and to move from belief to facts.

2) The use of soil moisture measurements to monitor the effect of water/soil moisture conservation measures

The TDR-technique presently used in the monitored catchments has proved to be a useful tool to measure changes in soil moisture. Thus, in Mazombe where insufficient soil moisture is one of the major constraints on crop production, the use of soil moisture measurements could be a important monitoring tool to study the effect of different types of soil moisture conservation measures, by measuring possible reductions in evapotranspiration or increases in infiltration. Also, it could be used as a tool to measure the possible competition for water between annual crops and various tree species used in agroforestry.

Field scale monitoring of the effect of soil and water conservation measures

The Water Resources Monitoring is monitoring on catchment scale. As such it monitors the integrated effects of the land use and catchment protection activities. Thus, the monitoring will not be able to monitor the effect of single conservation measures on the farmers field. For this purpose of getting more information of the effect of various soil and water conservation measures (not only in relation to soil erosion but soil fertility as well) the now abandoned experimental plot at Mgera, which was established as a joint effort between Sokoine University of Agriculture and the Royal Veterinary and Agricultural University in Copenhagen could be very useful. Furthermore, experience on a field scale from this plot and experience on catchment scale from the Water Resources Monitoring will complement each other. Thus, as also mentioned in the previous progress report, it is suggested that HIMA look into ways to utilize this site as both an experimental and demonstration site.

<u>Institutional aspects</u>

During the formulation of the Water Resources Monitoring all units within HIMA were involved, while the subsequent collection and primary analyses of data have been carried out by the staff from the Regional Hydrologist's Office in Iringa, except the readings of rain gauges and the evaporation pan which have been undertaken by local observers.

The possibility to collaborate with the Regional Hydrologist's Office has ensured a high quality of the collection of data. Thus, there is no reason to make any marked changes in the present arrangement for the collection of data. On the other hand, it is very important that at least one from each of the HIMA units (or at least from the agriculture and forestry units) should be involved in the forthcoming assessments of the implication of the results from the monitoring and that a closer collaboration between the hydrologists and HIMA-staff is established. However, the fact that the Regional Hydrologist participates in the Monday morning meeting once a month and that he already has participated in number of HIMA-activities, including the physical catchment survey and watershed management activities, will surely facilitate a closer collaboration in relation to the Water Resources Monitoring as well.

The Water Resources Monitoring has already resulted in a considerable strengthening of the Regional Hydrologist's Office. The allocation of a computer and printer and the subsequent training programme have resulted in a considerable increase in the capability of the office. The use of various software and programmes now makes it possible to carry out analyses that were earlier impossible or very time-consuming with pen and a piece of paper. This is important as the present problem at the Mtera Reservoir and the increased attention focused on the management of the water resources in the Great Ruaha River Basin have increased the office's workload considerably. E.g. both TANESCO and the Rufiji Basin Water Office have requested the office to undertake an increasing number of activities recently.

Thus, further training activities for the office as suggested by both the Regional Hydrologist and HIMA are recommended. Part of this training should include training in assessing the impact of the land use and project activities on the water resources. This part of the training programme should include a few persons from HIMA as well. Based on this training it is proposed that the next yearly report should be worked out as a joint effort between the hydrologists and HIMA - possibly with limited assistance from a consultant.

The Water Officer for the Rufiji Basin Water Office has expressed interest in using the results from the monitoring as well as participating in some of the overall analyses. As the Regional Hydrologist also is interested in such collaboration, it is highly recommended that the Water Officer participates in the analyses. His broad knowledge of the use of computers will also be an important support to the Regional Hydrologist's Office.

# 1. INTRODUCTION

## 1.1 Background

In January 1990 the DANIDA-financed Iringa Soil and Water Conservation Project, better known as HIMA(Iringa), started in Mazombe and Kilolo Divisions in Iringa District in the Southern Highlands of Tanzania.

The long term objectives of the project are that farmers should practice and benefit from improved, sustainable agriculture and natural resource management by the end of the project in 2005. The major components in the project activities are: Soil and water conservation, afforestation, agricultural extension, and community participation.

Apart from improving the conditions for agricultural production it is envisaged that the conservation measures and sound agricultural practices eventually will improve the water resources in terms of quantity as well as quality.

However, whether different land use systems, natural or man-managed, improve or deteriorate the water resources, and especially to which extent, have been a cause of controversy and debate. E.g. the effect of trees on the water quantity has involved very conflicting statements, and so has the effect of fertilizers on the water quality. One of the reasons is that there are very few data regarding the effects of land use practice on the water resources, especially in humid tropical climate. Furthermore, the hydrological response is a combination of climate, catchment characteristics, and human activity. Thus the effect may vary from region to region, depending on local climate and catchment characteristics.

Thus in 1992 it was decided to establish a Water Resources Monitoring Component at HIMA (Iringa) and from April 1993 a continuous monitoring has taken place.

## 1.2 The purpose and the content of the present report

The main aims of the present report are:

1) to present the data which have been collected since the start of the monitoring in April 1993 and until the end of the first full "water year" in October 1994

2) to analyze the data in relation to the original objectives of the monitoring as well as issues which have been raised by HIMA during the course of the monitoring

Although the report covers the first 1½ years of the monitoring, the presentation and analyses of the data collected within the first "water year", i.e. November 1, 1993 to October 31, 1994 will be emphasized in this report.

Some of the hydrological terms used and issues discussed in the report may be rather new to some within the HIMA project. Thus, it has been attempted to give a short explanation of the terms the first time they are used. Furthermore, quite a number of figures and tables have been included in order to present as many of the key data as possible and facilitate the reading of the report. Also, as it is envisaged that the report will be distributed to a variety of persons and projects outside the HIMA project, including hydrologists from other parts of the country, it has been aimed at giving a proper documentation of how the results are arrived at.

This has implied that parts of the report have become quite bulky. Thus, the major findings are summarized in the executive summary. The recommendations arrived at, based on the findings, are also found in the executive summary.

The main objectives of the Water Resources Monitoring are outlined in chapter 2.

The monitoring programme, monitoring area, instrumentation, and monitoring activities, have been described in details in a previous report (Lørup, 1993) but are briefly summarized in chapter 3.

Chapter 4 gives a comprehensive presentation and analyses of the quantitative aspects of the monitoring. On the basis of differences in total yearly runoff, dry season runoff and low flow, and peak flows during heavy rainfall events, the impacts of the different types of land use practice on the quantitative aspects of the water resources are discussed.

Chapter 5 gives a corresponding presentation and analyses of the impacts of the different types of land use practices on the qualitative aspects of the water resources.

## 1.3 Acknowledgements

This report is a result of the joint effort between HIMA (Iringa) and the Regional Hydrologist's Office in Iringa which have been responsible for the daily activities in terms of data collection and analyses, overall planning and logistical support. Although land and water resources are closely linked together, such collaboration between institutions responsible for management of land resources and water resources are not common in Iringa Region. In this respect I want to express my sincere gratitude to both HIMA and the staff at the Regional Hydrologist's Office for having had the opportunity to participate in the establishment of this monitoring component at HIMA (Iringa). The helpfulness of HIMA (Iringa)-management and the CTA, Paul Kerkhof, at the HIMA RPMU and their fruitful ideas and interest in the monitoring have highly facilitated the establishment of this component within HIMA. Both in the office during training sessions or analyses and during field activities at remote gauging stations, the staff from the Regional Hydrologist's Office has shown a lot of interest, helpfulness and enthusiasm, which has made the work a big pleasure, both professionally and socially.

## 2 THE OBJECTIVES OF THE WATER RESOURCES MONITORING

The original aims of the Water Resources Monitoring Component at HIMA (Iringa) are:

- to monitor the impacts of the project's afforestation and soil and water conservation measures on the water resources within the project area and thereby provide inputs for planning of future HIMA activities.

- to develop a better general understanding of the impact of land uses practices in the project area, including afforestation and soil and water conservation measures, on the water resources.

During the course of the monitoring, strengthening of the capabilities and skills of the personnel at the Regional Hydrologist's Office through training activities has been suggested as an additional aim.

Agricultural hydrology has been included in some of the HIMA courses on soil and water conservation in order to improve the understanding of its role in relation to cultivation, and soil and moisture conservation in particular. In this context the experience and the results from the water resources monitoring may be a useful tool.

# 3 THE MONITORING PROGRAMME

## 3.1 Monitoring strategy

To assess the impact of the project activities and the land use and management practice, in general, on the quantity and quality aspects of water resources in terms of quantity as well as quality, catchment studies are the most appropriate approach. This is because: 1) smaller catchments are manageable physiographic units for water budgeting and 2) smaller catchments often make it possible to select catchments with a rather uniform land use. For field plot experiments no water budgeting is possible, and in river basins many different types of land use within the basin make it difficult to relate the hydrological response to a certain land use or change in the land use.

All the water leaving the catchment area is drained to a single point, the outlet of the catchment. At the outlet a stream gauging stations can be established to measure all the water flowing out of the catchment.

Apart from monitoring the effect on the water resources the observations and collected data will also reflect the processes taking place on the hillslopes in the catchment. For instance, the sediment transport and runoff during heavy rains will provide information about the extent of surface runoff and soil erosion. Similarly the chemical composition of the water provides information about nutrient losses from farmers' fields.

To measure the effect of various land uses and management practices on the water resources different catchment approaches can be used:

- Paired catchment studies, where the effect on the water resources of two or more catchments with different land use practices is compared. Ideally the catchments should be about the same size with similar soils, geology, topography, and climate, so that the differences in hydrological response between the catchments can be ascribed to the differences in land use practice only.

- Longitudinal studies, where a catchment under changing land use is monitored for a longer period, in order to evaluate the impact of the changing land use practice on the water resources.

The two methods can be considered complementary, and a combination of the two approaches is envisaged in the project monitoring. In the short-term the use of the paired catchment approach will make it possible to evaluate the differences in hydrological response from the various types of land use represented in the catchments. Furthermore, as the monitoring programme is planned to be carried out throughout the project period, i.e. until 2005, it will be possible to study more long term impacts on the water resources of the project activities (and changes in land use practice in general) within each of the catchments.

### 3.2 Monitoring area

During the first three years the monitoring is carried out in the following four catchments, which are all located in Kilolo Division 50 to 80 km south of Iringa:

**MGERA:** A forested (evergreen) catchment which is located within the New Dabaga/Ulangambi Forest Reserve 50 km south of Iringa (see figures 3.1 and 3.5). A minor part of the catchment (approximately 20%) is located outside the forest reserve, most of which is cultivated, with maize as the main crop.

**GENDAVAKI:** The catchment is located north of Bomalang'ombe village, 75 km south of Iringa (see figures 3.2 and 3.6). The major part of the catchment is cultivated, with maize as the dominant crop. Only few conservation measures are in existence.

**MUHU:** The catchment is partly located south of Bomalang'ombe village and partly inside the village, 80 km south of Iringa (see figures 3.3 and 3.7). It is bordering the Ihaka catchment to the east, and it is one of the catchments within the HIMA area that have been given high priority. The main part of the catchment is cultivated (about 67%), with maize as the dominant crop. The implementation of soil and water conservation measures is still on a small scale but the rate of adoption seems to have increased recently.

**IHAKA:** The catchment is bordering the Gendavaki catchment to the north and the Muhu catchment to the west (see figures 3.4 and 3.8). It is similar to the Muhu catchment, although slightly steeper and with a broader valley bottom. Likewise Muhu it lies within the HIMA priority area. The main part of the catchment is cultivated with maize as the dominant crop. The implementation of soil and water conservation measures is still on a small scale but the rate of adoption seems to have increased recently.

The catchments are almost of the same size, varying from 5.03 to 5.15 $km^2$. The yearly rainfall is also of the same magnitude - at least for the first water year - varying from 1128 mm to 1257 mm. The main physical characteristics for each of the catchments are summarized in Table 3.1 and the locations of the catchments can be seen on Figure 3.10.

### 3.3 Activities included in the monitoring

The data collection is coordinated by the Regional Hydrologist in Iringa and the water quantity data collection is carried out by the technicians from the Regional Hydrologist's Office in Iringa while the collection and analysis of water samples are made by the Regional Water Engineer's water quality laboratory in Iringa. Construction of gauging stations and installation of instruments were carried by the staff from the Regional Hydrologist's Office with logistical support from HIMA and the TUD-Adviser. The latter also assisted in the installation of the automatic weather station and the establishment of the soil moisture stations as this included equipment and procedures which were new to the hydrology office at that time.

**Figure 3.1** - *Looking upstream in the* ***Mgera*** *catchment at the boundary to the Forest Reserve. When leaving the Forest Reserve the stream passes through a valley bottom where vinyungu cultivation is practised in part of it. Burning next to the forest boundary can be seen to the right.*

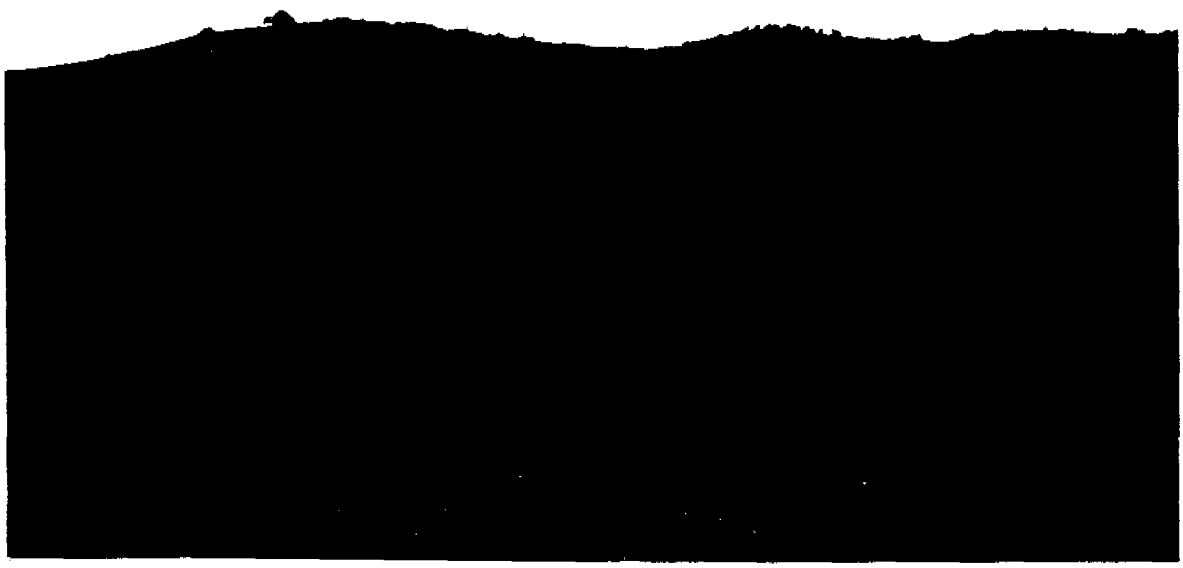

**Figure 3.2** - *The* ***Gendavaki*** *catchment with cultivation on steep slopes which are characteristic for both Gendavaki, Muhu and Ihaka catchments.*

**Figure 3.3** - *The residential area in Bomalang'ombe in the upper part of the* ***Muhu*** *catchment. The lower part of the footpath seen to the left has developed into a gully which ends up in the stream.*

**Figure 3.4** - *Trash lines in a sub-catchment in the upper part of the* ***Ihaka*** *catchment where some of the steepest slopes in the four monitored catchments are found. Almost all the farmers in this sub-catchment have agreed to start implementing soil conservation measures. It is planned that vetiver grass shall be planted along the trash lines.*

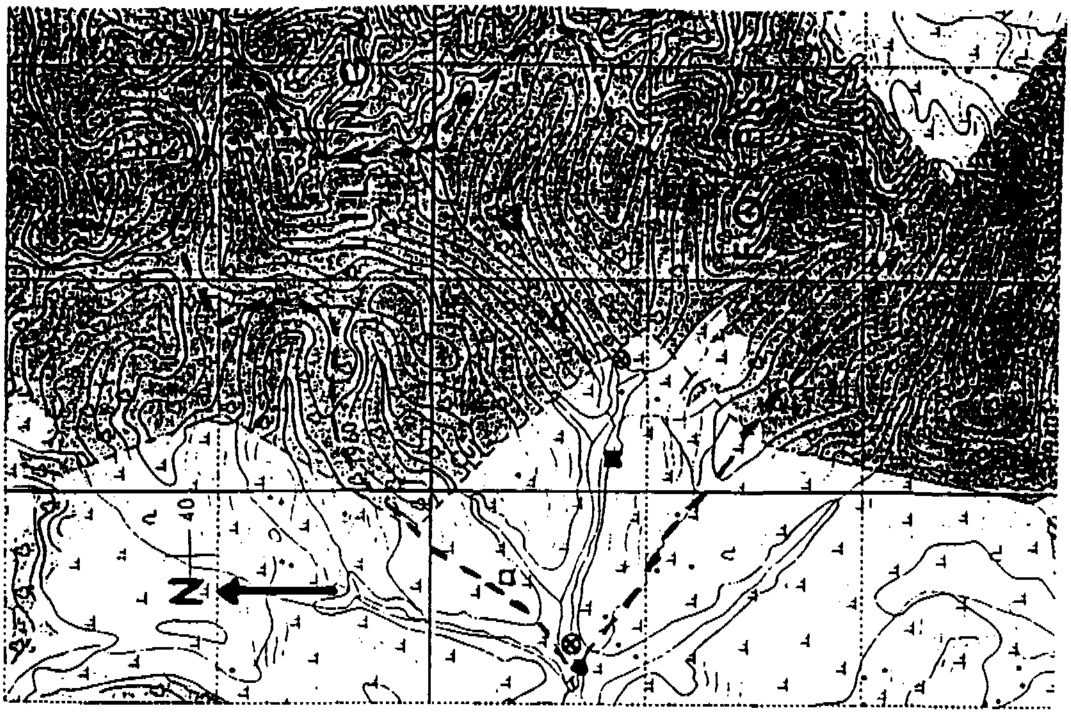


**Figure 3.5** - *The Mgera catchment with the location of the various gauging stations: ●) Stream gauging station, □) Rain gauge station (standard), ■) Rain gauge station (standard+automatic), △) Soil moisture station and ⊗) Site for collection of water samples (1:36.000).*

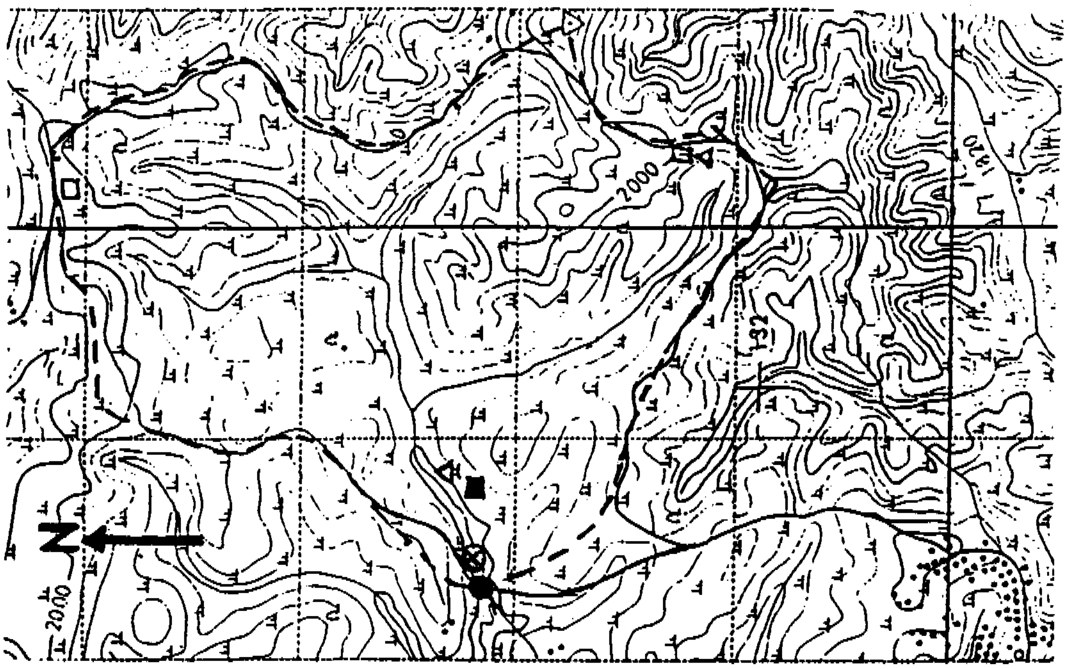


**Figure 3.6** - *The Gendavaki catchment with the location of the various gauging stations: ●) Stream gauging station, □) Rain gauge station (standard), ■) Rain gauge station (standard+automatic), △) Soil moisture station and ⊗) Site for collection of water samples (1:36.000).*

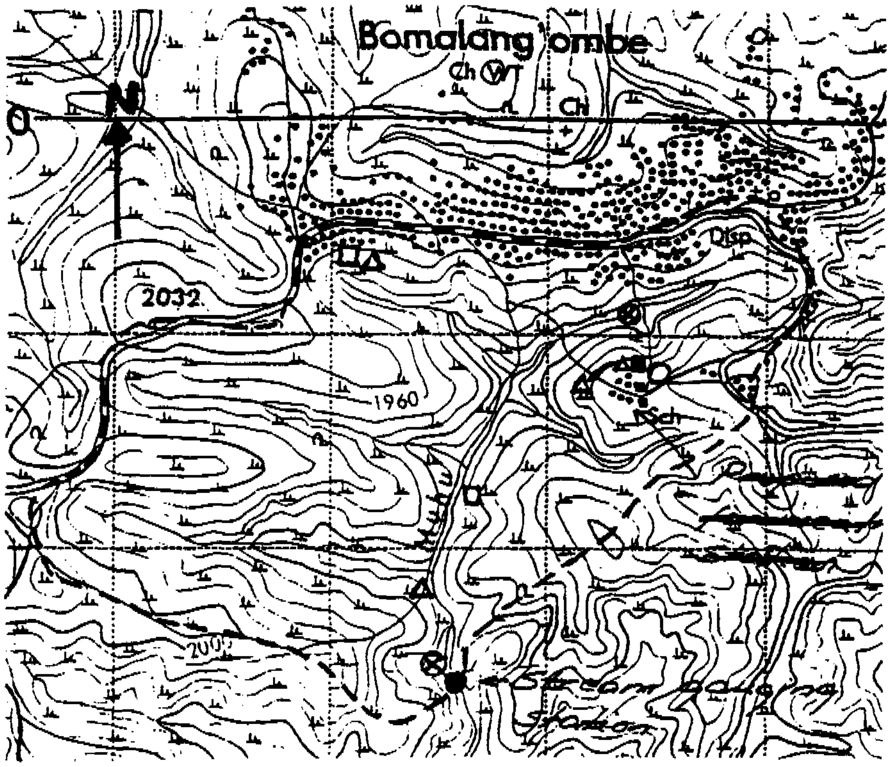


**Figure 3.7** - *The Muhu catchment with the location of the various gauging stations:* O) *Climatic station,* ●) *Stream gauging station,* □) *Rain gauge station (standard),* ■) *Rain gauge station (standard+automatic),* △) *Soil moisture station and* ⊗) *Site for collection of water samples (1:36.000).*

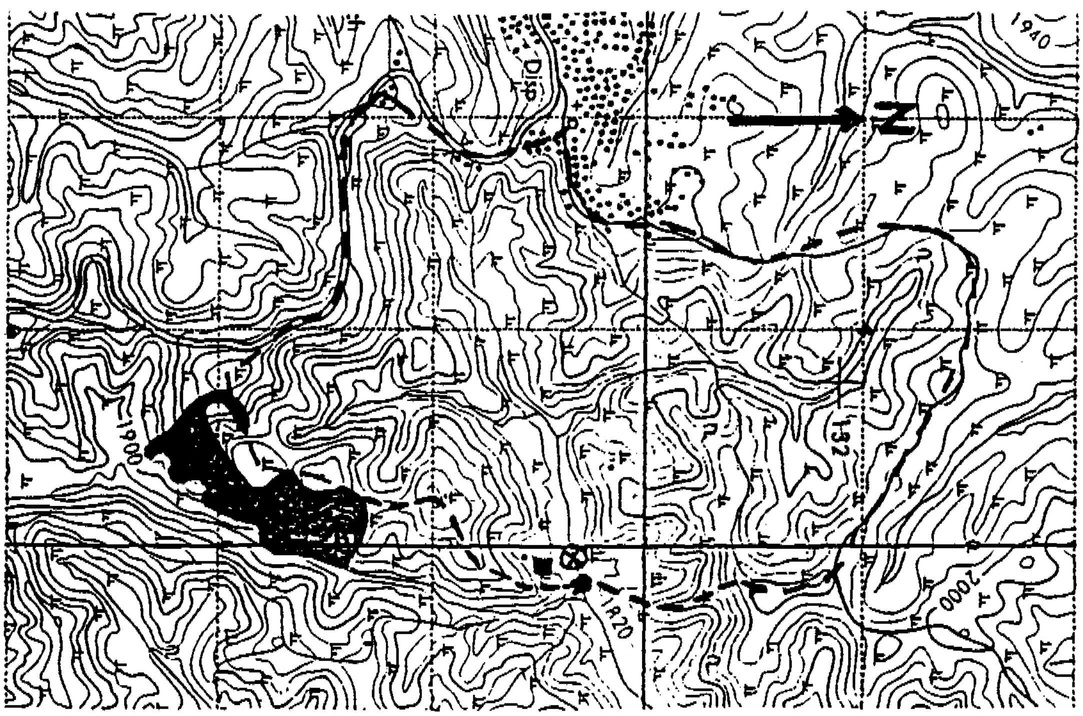


**Figure 3.8** - *The Ihaka catchment with the location of the various gauging stations:* ■) *Rain gauge station (standard+automatic),* ●) *Site for low flow measurements and* ⊗) *Site for collection of water samples (1:36.000).*

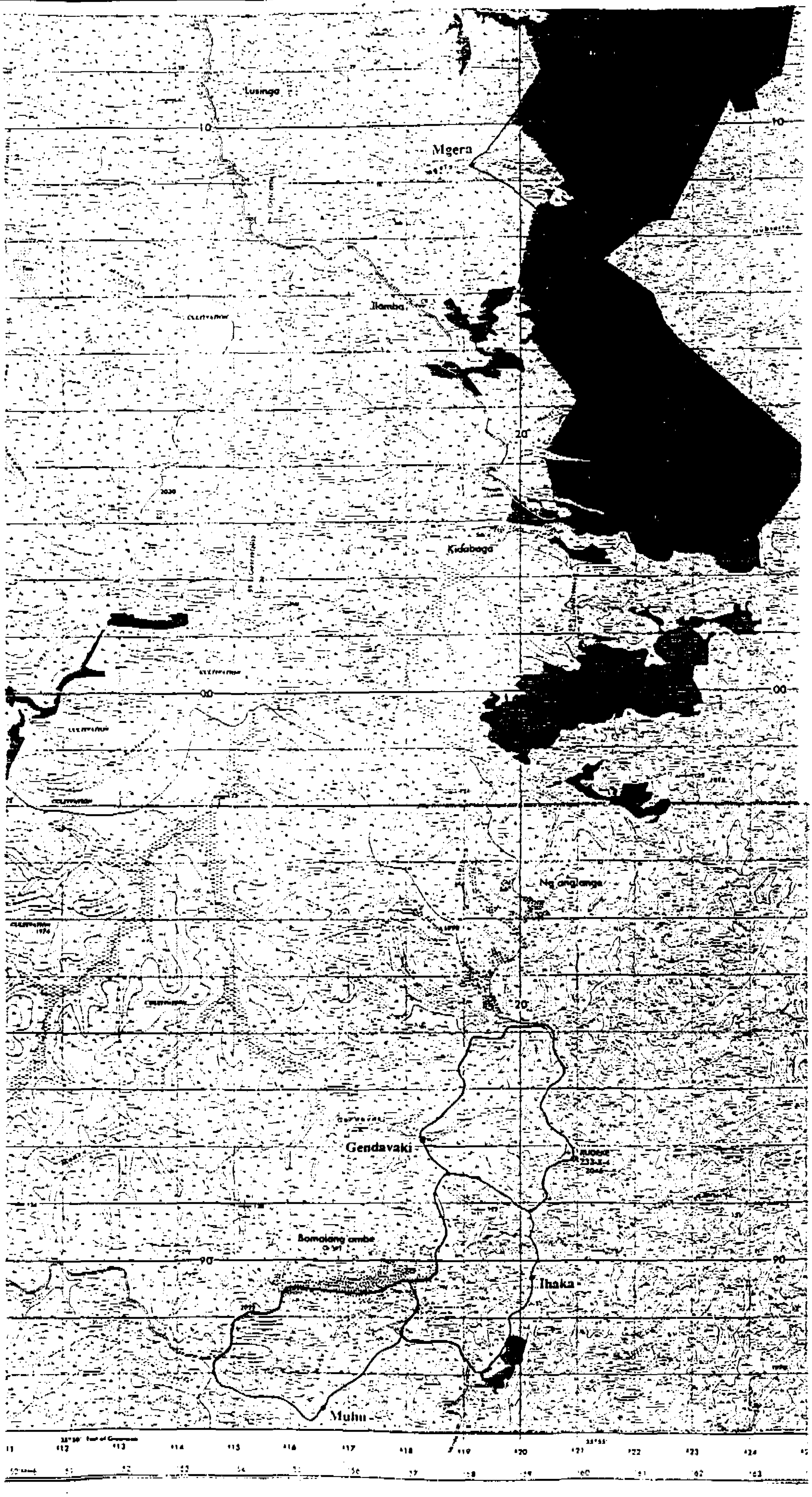


**Figure 3.10** - *The location of the four catchments 50-80 km south of Iringa: Mgera, Gendavaki, Muhu and Ihaka (1:100.000).*

**Table 3.1** - *The main physical characteristics of the catchments presently included in the Water Resources Monitoring Programme.*

| | Mgera | Gendavaki | Muhu | Ihaka |
|---|---|---|---|---|
| Catchment size ($km^2$) | 5.15 | 5.13 | 5.14 | 5.03 |
| Altitude range (m) | 1890-2030 | 1895-2045 | 1850-2030 | 1815-2060 |
| Average slope gradient (%) | 20-30 | 20-30 | 20-30 | 20-35 |
| Yearly rainfall 1993/94 (mm) | 1257 | 1231 | 1128 | 1136 |
| Vegetation[a] (approximately) | 85% forest 15% cultivated[d] | 70 % cultivated 30% grassland/bush forest/woodland | 67% cultivated 23% bush/grassland 10% forest/woodland | 70 % cultivated 30% grassland/bush forest/woodland |
| Geology | Pre-cambrian metamorphic rocks mainly composed of gneiss, amphibolites granulates, schists, quartzite and migmatites[c] | | | |

a) The figures for Gendavaki and Ihaka are very rough estimates as no proper land use survey has been carried out yet.
b) A portion of this area is swampy
c) According to URT/DANIDA (1987) and Mrema *et al.* (1992)
d) According to a land use survey using ground truth and Panoramic Photography (Krogh, 1992)

### 3.3.1 Monitoring of water quantity

To assess the impact of the project activities on the water quantity, e.g. surface runoff, flood risks, and the low flow during the dry season it is necessary to measure the different components of the hydrological cycle (rainfall, runoff, evaporation, and water storage) in order to make water balances for each of the monitored catchments. The various components of the hydrological cycle are outlined in Figure 3.9. On the basis of the water balances it is possible to make a quantitative evaluation of water resources and their change under the influence of man's activities. The following components of the hydrological cycle are monitored:

**Rainfall:** Rainfall measured at 2-3 manual rain gauges and one automatic rain gauge in each catchment. The manual rain gauges are read daily, whereas the automatic rain gauges record continuously and thus provide information on rainfall intensities, which, more than the total daily rainfall, determines the severity of soil erosion.

**Runoff:** The runoff is measured at the stream gauging station at the outlet of the catchments. Automatic water level recorder and staff gauges are installed. Discharge measurements are carried out regularly to establish rating curves (relation between water level and streamflow)

**Climate:** The following climatic parameters are recorded continuously at an automatic weather station in the Muhu catchment: Temperature, relative humidity, wind speed, solar radiation, wind direction, and rainfall, from which the potential evapotranspiration can be estimated. The climatic station also includes an evaporation pan where evaporation from a free water surface is recorded daily.

**Soil moisture:** Soil moisture is measured at two sites in each catchment. It is measured by the TDR-method. Measurements are made monthly to a depth of 1.25 m and at a few of the sites down to 2.65 m. The measurements are used to calculate the changes in soil moisture storage and to estimate the actual evaporation during the dry season. Furthermore, the results can also be used to assess the infiltration conditions.

**Sediment transport:** The plan is to measure sediment transport, but it has not started yet. This will be spot measurements, which will be done regularly during the rainy season and with a lower frequency during the dry season. It should help estimating the extent of soil erosion in the catchments.

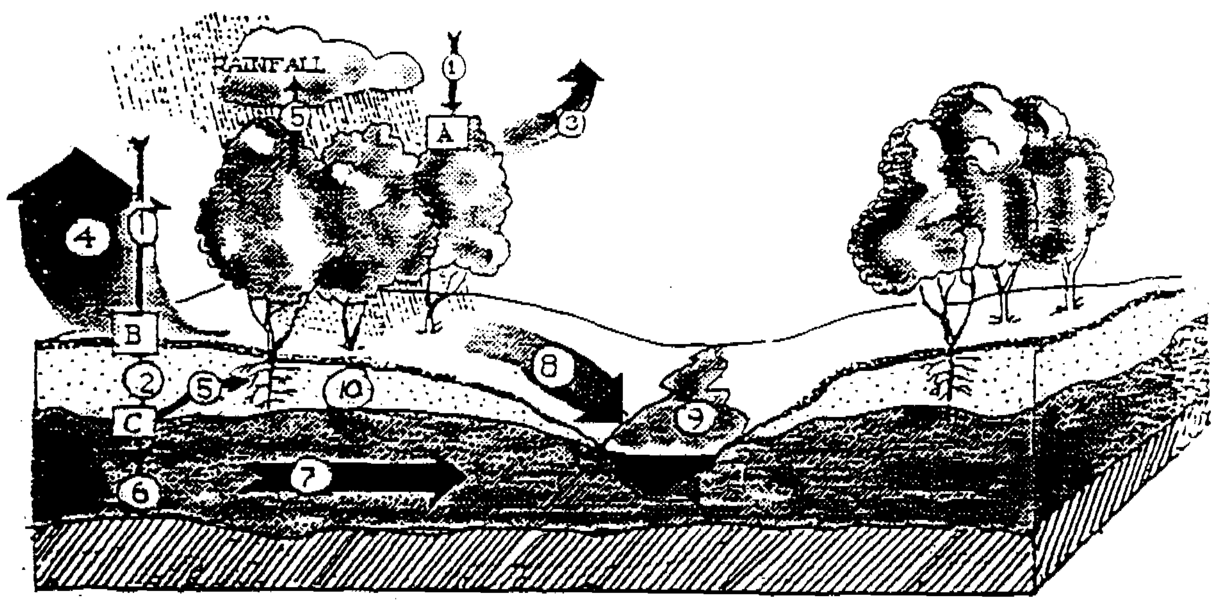


**Figure 3.9** - *A schematic illustration of the hydrological cycle, showing the various possible routes of the rainfall. 1) Rainfall, 2) Infiltration, 3) Interception at and subsequent evaporation from the vegetation cover, 4) Evaporation from the soil surface, 5) Water uptake by and transpiration through the vegetation, 6) Groundwater recharge, 7) Groundwater flow, 8) Surface runoff (overland flow), 9) Streamflow (discharge) and 10) Soil moisture.*

However, in Ihaka the monitoring only includes measurements of rainfall, discharge measurements at the end of the dry season for low flow determination, and water quality analysis. Thus most of the results and analysis presented in the succeeding chapters originate from Mgera, Gendavaki and Muhu. The location of the different gauging stations in each of the catchments are shown in figures 3.5 to 3.8. A more detailed description of the monitoring activities, including instrumentation and data collection and analyses can be found in Lørup (1993).

### 3.3.2 Monitoring of water quality

The aim of the water quality analysis is to measure the present state of the water quality in each of the catchments, to evaluate the quality of the water for domestic use, to compare the quality of water originating from areas with different types of land use practice and to measure the possible impact on the water quality by land use changes within each of the four catchments.

Water samples are collected and analyzed monthly during the rainy season and every second or third month during the dry season. The samples are collected at the outlet of each of the catchments. Furthermore, in Muhu catchment samples are collected where the villagers fetch water for domestic use and in Mgera samples are collected where the stream leaves the Forest Reserve. Later on samples may also be collected at other points e.g. at the outlet of sub-catchments where intensive conservation measures have been undertaken or where the water is feared to be heavily polluted. Furthermore, the project plans to extend the water quality analyses to other project areas of special interest outside the four catchments.

Monthly collection and analysis of water samples include:

- bacteriological analysis (faecal coliform)
- chemical analysis (e.g. nitrogen, calcium, magnesium, chloride, iron)
- physical measurements (e.g. pH, colour, conductivity, turbidity)

It is also the aim to carry out some few pesticide analyses during the rainy season.

### 3.3.3 Land use surveys and soil analyses

To relate the monitoring results to land use practices in the catchments it is necessary that the land uses within the catchments are precisely and regularly described. A detailed land use survey of all of the catchments is planned in 1995. Also, soil sampling and analysis for Mgera, Gendavaki and Muhu are planned to be undertaken in 1995. Measurements of saturated infiltration capacity have earlier been carried out in Muhu and Mgera (Krogh, 1992).

### 3.3.4 Training programmes

As an important part of the activities a training programme has been carried out for the personnel at the Regional Hydrology Office in Iringa. Among other things this has included the use of some of the new methods for data collection which have been introduced with the monitoring programme (e.g. the TDR-method for soil moisture measurements and operation of the automatic weather station) and training in computer use for data analysis and report writing. Furthermore, agricultural hydrology and water resources monitoring have been included in some of the courses in soil and water conservation within the project.

# 4. WATER QUANTITY: DATA PRESENTATION AND ANALYSIS

In this chapter all the data regarding water quantity (i.e. rainfall, runoff, soil moisture and climatic data) collected since the start of the monitoring in April 1993 until October 31, 1994 will be presented and discussed. However, the data covering the first full water year, i.e. from November 1, 1993 until October 31, 1994, will be emphasized, including the establishment of a yearly water balance for this period.

Rainfall, runoff, soil moisture and climatic data will shortly be presented separately. The reliability of data and the differences between the recordings from the various stations will be discussed. At the end of the chapter a water balance for the three catchments with stream gauging (Mgera, Gendavaki and Muhu) will be established, and the differences in hydrological responses will be discussed in relation to the specific land use practice within each of the catchments. Differences in total yearly runoff, low flow during the end of the dry season, and peak flows during rainstorm events will be discussed.

## 4.1 Rainfall

### 4.1.1 Collection and quality of rainfall data

Almost all the eight standard rain gauges have been read daily by the local observers (most often the farmer on whose field the rain gauge has been placed. A number of daily recordings are missing at MU-II. For the other stations the number of missing recordings is less than 10 (out of a total number of more than 4000 readings).

The hydrology technicians have visited the stations regularly during the whole period of the monitoring period, and charts have been collected weekly from the automatic rain gauges as planned. However, during the period November 1993 to April 1994 a number of recordings are missing from the rain gauge at Mgera due to problems with the siphoning of the rain gauge during this period. Similarly for the automatic rain gauge in the Muhu catchment, there are no recordings from August 5 to December 29, 1993 partly due to problems with the battery voltage of the automatic weather station caused by a manufacture failure and partly due to loss of data when the motherboard of the old computer had broken down. However, data exist from the corresponding standard rain gauges for these periods at both of the stations. Consequently, the missing data do not present a serious problem for the establishment of the annual water balances.

The quality of the rainfall data has been evaluated regularly in order to ensure necessary adjustments to be made when/if needed. The routines for check of rainfall data have included:

a) Misreadings, misplaced decimal points, and errors when entering the recordings into files
b) Comparison between recordings from standard and automatic rain gauges at the four stations where both standard and automatic rain gauges are placed

c) Comparison between recordings from rain gauges at different stations mainly within the same catchment in order to assess whether there is consistency between the readings

In general the quality of the rainfall data is encouraging. The only exception is MU-II which is the only station with more than a few missing data, and where there is some inconsistency with the recordings from the other stations at especially Muhu. The inconsistencies from this station include a number of days where no rain was recorded at this station while a considerable amount of rain was recorded at all the 7 other standard rain gauges. Therefore the average rainfall for Muhu only have been based on the recordings from MU-I and MU-III rainfall stations.

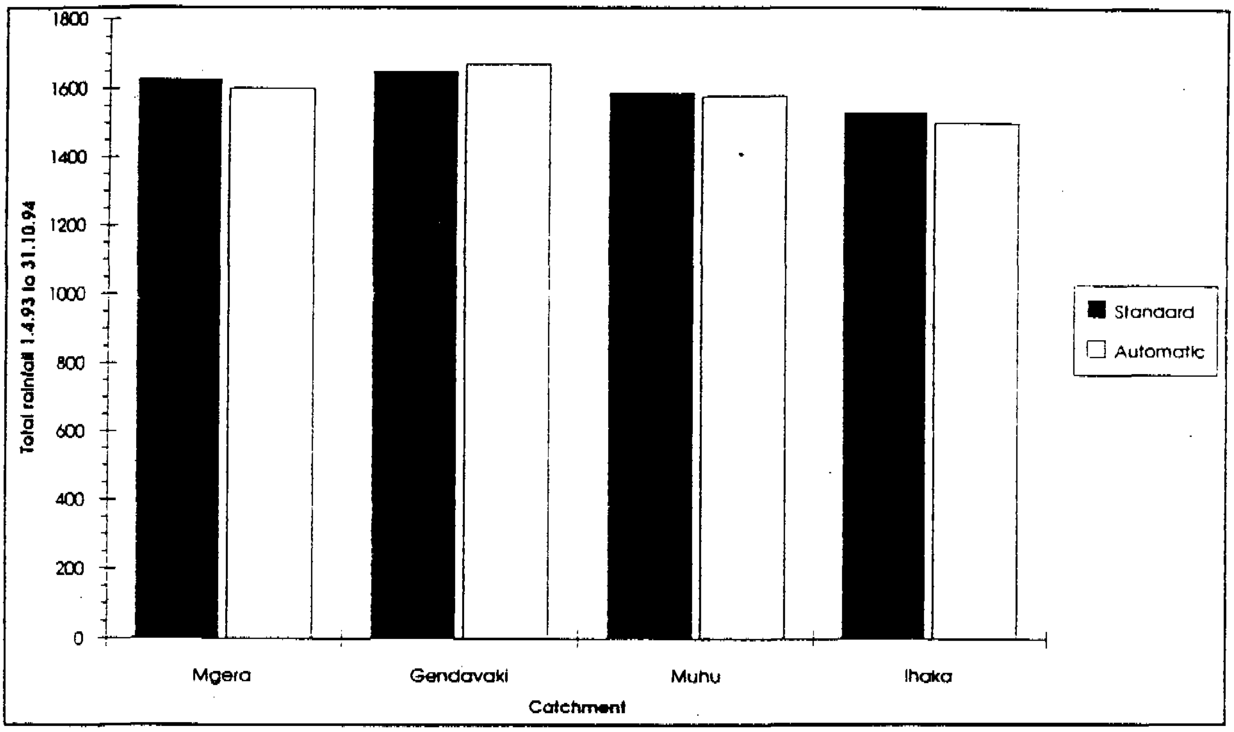


**Figure 4.1** - *Comparison between rainfall recordings from standard and automatic rain gauges and rainfall recordings between the catchments.*

During the establishment of rainfall stations and installation of instruments it was decided for each catchment to place the automatic rain gauge together with one of the standard rain gauges in order to be able to make a comparison between the readings from the two types of rain gauges. For all four catchments Table 4.1 gives the monthly values from the adjacent standard and automatic rain gauges, respectively. For the whole period the differences in recordings from the two types of rain gauges are rather small (as it also is illustrated in Figure 4.1) varying from 0.6 to 1.8 per cent. On a monthly basis the differences are larger, especially February and March 1994, where the largest deviations are found for most of the catchments. On a daily basis (not shown in Table 4.1) some rather big deviations have be found. However, this has primarily been due to the fact that the standard rain gauges have not always been read at 9.00 am whereas the automatic rain gauges are always analyzed from 9.00 to 9.00 am). Thus considerable deviations between the readings for standard and automatic rain gauges may result on those days with heavy rains during the morning hours. Therefore, when records for a number

**Table 4.1** - *Comparison between standard (Std.) and automatic (Aut.) rain gauges for the period April 1, 1993 to October 1, 1994. The two types of rain gauges are placed at the same location for each of the catchments. Numbers are in mm.*

| Month | Muhu | | Ihaka | | Gendavaki | | Mgera | |
|---|---|---|---|---|---|---|---|---|
| | Std. | Aut. | Std. | Aut. | Std. | Aut. | Std. | Aut. |
| Apr-93 | 268.0 | 263.0 | 275.4 | 275.3 | 298.0 | 298.0[c] | 259.4 | 260.8 |
| May-93 | 67.7 | 62.0 | 60.1 | 66.0 | 69.3 | 70.7 | 51.7 | 52.9 |
| Jun-93 | 6.7 | 3.8 | 9.0 | 11.4 | 13.8 | 13.9 | 5.4 | 8.3 |
| Jul-93 | 4.4 | 13.0 | 6.0 | 3.5 | 17.3 | 17.0 | 13.5 | 13.9 |
| Aug-93 | 10.2 | 10.7 | 10.8 | 10.4 | 9.2 | 8.1 | 4.9 | 6.0 |
| Sep-93 | 10.2 | 10.2[b] | 6.5 | 6.8 | 6.2 | 6.4 | 3.2 | 3.1 |
| Oct-93 | 24.8 | 24.8[b] | 25.8 | 24.0 | 26.2 | 25.7 | 13.1 | 14.0 |
| Nov-93 | 41.1 | 41.1[b] | 34.5 | 34.4 | 28.7 | 27.2 | 17.1 | 21.3 |
| Dec-93 | 91.0 | 91.0[b] | 120.1 | 118.9 | 136.3 | 135.9 | 30.9 | 31.9 |
| Jan-94 | 180.1 | 182.2 | 176.0 | 177.1 | 177.6 | 176.3 | 240.8 | 240.9 |
| Feb-94 | 181.8 | 172.8 | 198.8 | 188.4 | 278.9 | 295.5 | 325.7 | 322.6 |
| Mar-94 | 351.4 | 331.0 | 221.4 | 220.0 | 169.6 | 167.1 | 364.9[a] | 333.6[a] |
| Apr-94 | 140.6 | 139.6 | 159.1 | 145.2 | 168.2 | 171.0 | 123.9 | 112.5 |
| May-94 | 140.5 | 154.0 | 159.6 | 154.7 | 167.7 | 173.3 | 128.1 | 136.1 |
| Jun-94 | 0.0 | 2.6 | 0.5 | 1.0 | 1.4 | 2.3 | 2.8 | 2.0 |
| Jul-94 | 7.3 | 9.2 | 6.6 | 7.7 | 7.0 | 6.2 | 6.5 | 7.1 |
| Aug-94 | 16.3 | 14.6 | 11.1 | 12.0 | 15.2 | 15.7 | 5.7 | 7.0 |
| Sep-94 | 6.0 | 9.2 | 7.8 | 8.5 | 8.8 | 9.2 | 1.5 | 1.6 |
| Oct-94 | 39.3 | 43.6 | 40.5 | 37.2 | 51.8 | 52.6 | 25.6 | 25.0 |
| Total | 1,587.40 | 1,578.40 | 1,529.60 | 1,502.50 | 1,651.20 | 1,672.10 | 1,624.70 | 1,600.60 |
| Deviation (mm) | 9.0 | | 27.1 | | - 20.9 | | 24.1 | |
| **Deviation (%)** | **0.6** | | **1.8** | | **- 1.3** | | **1.48** | |

a) It is likely that the rather large deviation for Mgera during this month is due to problems experienced with the automatic rain gauge during this period.

b) As the recordings from the weather station was lost during the breakdown of the motherboard of the old computer, recordings from the standard rain gauge are used - therefore the same value appears for standard and automatic rain gauge

c) The data from the automatic rain gauge from this month were stolen - thus the values from the standard rain gauge are used of subsequent days are compared, there is a good consistency between records from the corresponding rain gauges. The fact that the records from the standard rain gauges match well with the values from the corresponding automatic rain gauges indicates a high reliability of the readings made by the local observers.

As part of the data check of the records from the standard rain gauges each of the recordings from each rain gauge was compared with the other rain gauge(s) in the same catchment and with rain gauges in nearby catchments in order to evaluate the consistency in the recordings. Both on a daily basis as well as on monthly basis (see Table 4.2) there is a good consistency between the readings from the various stations. Within each of the catchments the variation of the total amount of rainfall recorded at the standard rain gauges is largest for Muhu (15.2%) and less for Gendavaki and Mgera, 2.9% and 4.4%, respectively. With the size of the catchments of approximately 5.1 km$^2$ and rather large differences in altitude within each of the catchments such differences in rainfall are quite likely. For all the 3 catchments the highest rainfall is recorded at the station which is located at the highest elevation and the most easterly, which also is to be expected. In order to check whether the difference between Mu-I and MU-III might be due to changes in operation of either of the stations a double mass for the two stations has been drawn in figure 4.2. The straight line indicates that there have *not* been any changes in either the physical environment or the recording practice by the gauge reader which may have caused errors.

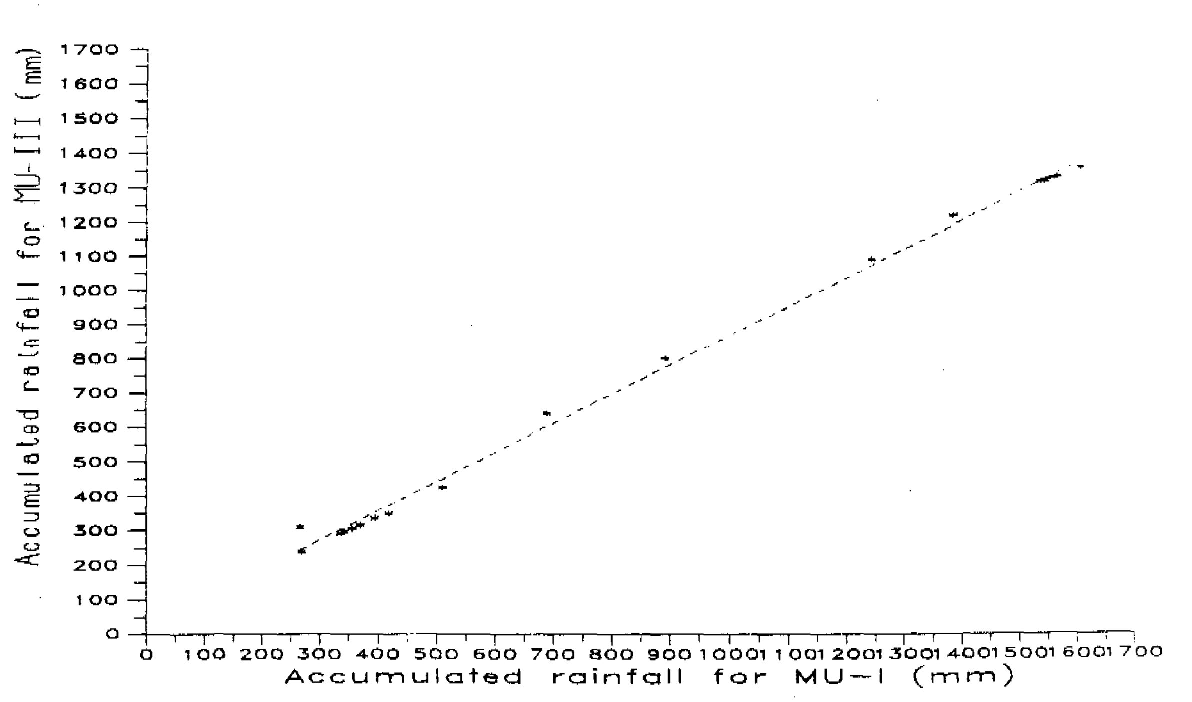


**Figure 4.2** - *Double mass curve showing the accumulated rainfall for Mu-I and MU-III from 1.4.93 to 31.10.94.*

Based on the discussion above it can be concluded that rainfall data for all the stations exist for the whole period and are of good quality.

**Table 4.2** - *Monthly rainfall from all the standard rain gauges from 1.4.93 to 31.10.94.*

| PERIOD | MU-I | MU-II[a] | MU-III | GE-I | GE-II | MG-I | MG-II | IH-I |
|---|---|---|---|---|---|---|---|---|
| Apr-93 | 268.0 | 222.6 | 240.4 | 298.5 | 304.0 | 259.4 | 235.5 | 275.4 |
| May-93 | 67.7 | 53.9 | 52.7 | 69.3 | 68.5 | 51.7 | 45.0 | 60.1 |
| Jun-93 | 6.7 | 9.4 | 4.6 | 13.8 | 12.1 | 5.4 | 4.0 | 9.0 |
| Jul-93 | 4.4 | 15.7 | 7.7 | 17.3 | 12.4 | 13.5 | 15.5 | 6.0 |
| Aug-93 | 10.2 | 3.4 | 6.5 | 9.2 | 11.2 | 4.9 | 4.4 | 10.8 |
| Sep-93 | 10.2 | 6.6 | 5.3 | 6.2 | 6.0 | 3.2 | 3.2 | 6.5 |
| Oct-93 | 24.8 | 6.9 | 19.0 | 26.2 | 33.9 | 13.1 | 10.0 | 25.8 |
| **Total April 93 - October 93** | **392** | **319** | **336** | **441** | **448** | **351** | **318** | **394** |
| Nov-93 | 41.1 | 5.1 | 24.5 | 28.7 | 36.8 | 17.1 | 16.7 | 34.5 |
| Dec-93 | 91.0 | 42.0 | 76.3 | 136.3 | 153.2 | 30.9 | 20.5 | 120.1 |
| Jan-94 | 180.1 | 182.5 | 215.0 | 177.6 | 168.8 | 240.8 | 221.9 | 176.0 |
| Feb-94 | 181.8 | 175.9 | 166.0 | 278.9 | 257.9 | 325.7 | 321.0 | 198.8 |
| Mar-94 | 351.4 | 295.5 | 289.9 | 169.6 | 209.5 | 364.9 | 389.4 | 221.6 |
| Apr-94 | 140.6 | 120.3 | 128.6 | 168.2 | 173.9 | 123.9 | 116.3 | 159.1 |
| May-94 | 140.5 | 97.7 | 119.2 | 167.7 | 171.0 | 128.1 | 115.5 | 159.6 |
| Jun-94 | 0 | 0 | 0 | 1.4 | 0.9 | 2.8 | 2.5 | 0.5 |
| Jul-94 | 7.3 | 1.9 | 3.2 | 7.0 | 3.5 | 6.5 | 6.2 | 6.6 |
| Aug-94 | 16.3 | 1.4 | 9.7 | 15.2 | 17.0 | 5.7 | 5.1 | 11.1 |
| Sep-94 | 6.0 | 4.8 | 3.3 | 8.8 | 2.0 | 1.5 | 1.4 | 7.8 |
| Oct-94 | 39.3 | 32.2 | 25.1 | 51.8 | 57.2 | 25.6 | 23.2 | 40.5 |
| **Total for Nov 93 - Oct 94** | **1,195.40** | **959.30** | **1,060.80** | **1,211.20** | **1,251.70** | **1,273.50** | **1,239.70** | **1,136.20** |
| **Total for April 93 - Oct 94** | **1,587.40** | **1,277.80** | **1,397.00** | **1,651.70** | **1,699.80** | **1,624.70** | **1,557.30** | **1,529.80** |
| **Total average for each catchment Nov 93 - Oct 94** | **1,128[b]** | | | **1,231** | | **1,257** | | **1,136** |

a) The data for this station are considered to be of a rather low quality

b) This value is based on MU-I and MU-III, only, as the data from MU-II are assessed to be of too low quality.

### 4.1.2 Rainfall amounts, intensities, and temporal distribution

The monthly rainfall from all the standard rain gauges is presented in Table 4.2. The total average rainfall values for each catchment at the bottom of the table are average values of the rainfall records from the stations in the respective catchment. However, for Muhu the values are average values for MU-I and MU-III. These average values derived from the standard rain gauges will later be used to establish the water balance for the water year 1993-94. A later, more detailed analysis of rainfall distribution may result in another weighting of the stations.

As it appears from the table, both Table 4.1 and figure 4.1, the total rainfall during the period covered in this report (i.e. 1.4.93 to 31.10.94) is almost the same for the four catchments. In the three catchments with "full monitoring" (i.e. including a stream gauging and soil moisture stations) the total rainfall for the water year 1993-94 is almost the same for Mgera and Gendavaki, 1257 mm and 1231 mm, respectively, whereas the rainfall from Muhu is a bit lower, 1128 mm. Ihaka, which physically borders both Muhu and Gendavaki has a yearly rainfall similar to Muhu. The lower value at Muhu is mainly due to the lower rainfall at MU-III. The average value for the four catchments is 1188 mm. However, a number of years are needed in order to assess whether the yearly rainfall in general is similar for the catchments.

When evaluating the rainfall data and how the catchments have responded to the rainfall for the monitoring period April 93 to October 1994, it is important to know whether the rainfall recorded is above or below the long term average rainfall that can be expected in the area. However, the only historical rainfall records from the catchments are rainfall records from the school at Bomalang'ombe (close to the present location of MU-I) from 1974 to 1980. The average monthly values are presented in Table 4.3. The average yearly rainfall recorded during this period is 1353 mm which is 157 mm more than recorded during the 1993/94 water year and 87 mm more than during 1994. However, no continuous recording took place during 1974-80 as several months are missing, which may indicate that the reliability of the data is not good.

**Table 4.3** - *Monthly comparison between historical (1974-80) rainfall data and the values recorded since the start of the monitoring in April 1993. Both sets of data originate from standard rain gauges at the school in Bomalang'ombe and are presented in mm/month.*

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974-80 | 180.9 | 150.2 | 281.5 | 283.7 | 126.3 | 2.9 | 7.1 | 6.1 | 6.6 | 14.4 | 93.5 | 199.4 | **1353** |
| 1993 | | | | 268.0 | 67.7 | 6.7 | 4.4 | 10.2 | 10.2 | 24.8 | 41.1 | 91.0 | |
| 1994 | 180.1 | 181.8 | 351.4 | 140.6 | 140.5 | 0.0 | 7.3 | 16.3 | 6.0 | 39.3 | 28.8 | 173.8 | **1266** |

Although the catchments are situated less than 100 km from Iringa, it is interesting to notice that the average yearly rainfall for all the catchments for 1993-94 (1183.6 mm) and the historical rainfall records from Bomalang'ombe (1352.6 mm) are about twice as high as the average yearly rainfall recorded at Iringa (Nduli Airport) during the period 1959-79, namely 650 mm.

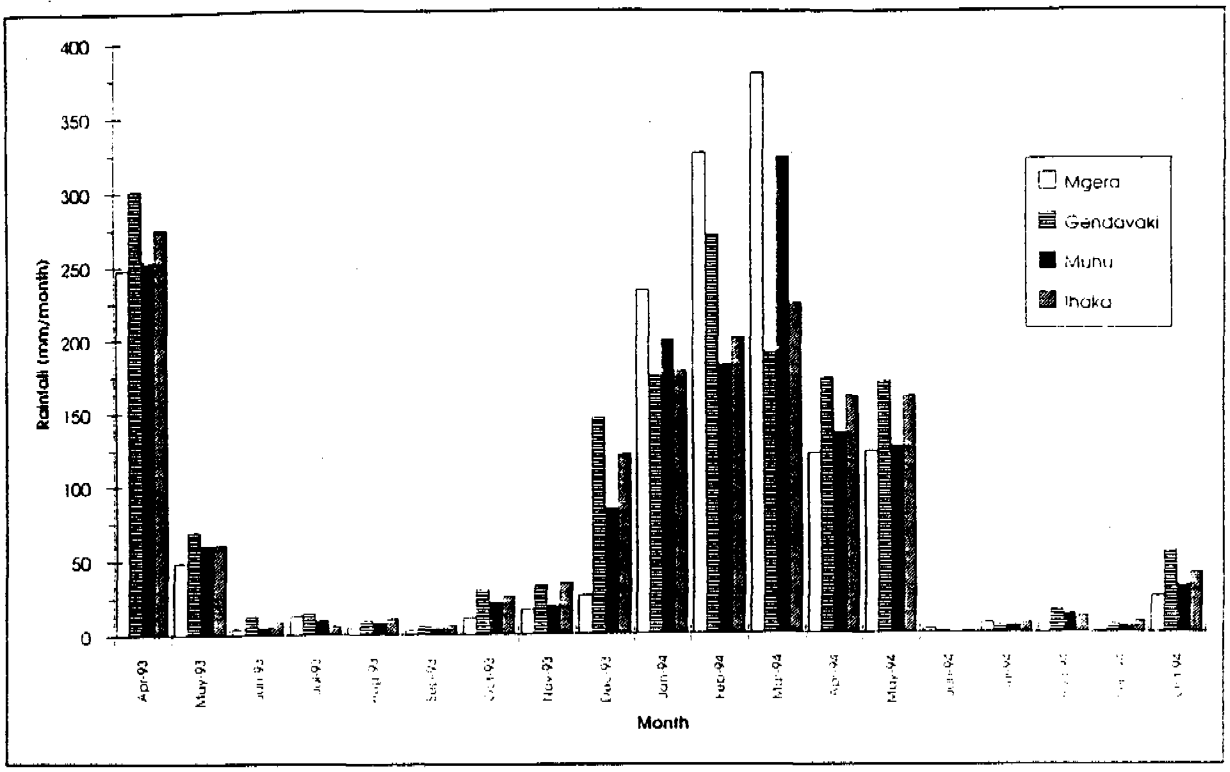


**Figure 4.3** - *Temporal variation of monthly rainfall for each of the four catchments.*

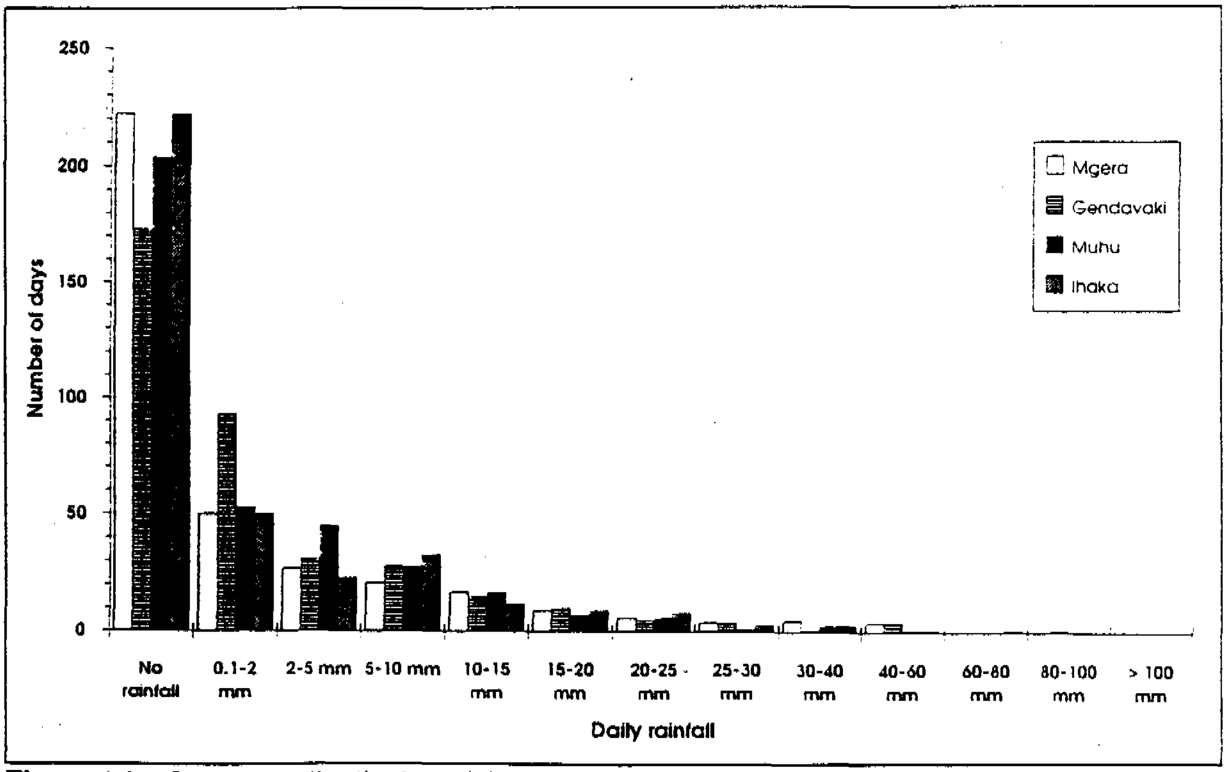


**Figure 4.4** - *Frequency distribution of daily rainfall amounts for all four catchments for the 1993-94 water year.*

Apart from the total amount of rainfall, the runoff amount and pattern from the catchments depend on the temporal distribution of the rainfall, including the time of the year, the daily amounts, and the rainfall intensities. The latter being the most important factor in relation to surface runoff and soil erosion during the rainstorms.

Table 4.2 shows that the temporal distribution of the rainfall in the respective catchments is very similar, which also clearly can be seen from Figure 4.3. For the water year 1993-94 most of the rainfall appeared during December to May with the highest amounts appearing in February and March, whereas there is very little rainfall from June to September.

The catchments also show large similarities in terms of the daily amount of rainfall as shown in figure 4.4. For most of the rainy days the amount of rainfall has been less than 10-15 mm. In Table 4.4 the daily rainfall amount for Muhu is compared with the daily max. 30-min rainfall intensity for Muhu.

As seen from Table 4.4 the daily max. 30-min rainfall was less than 2 mm (= 4 mm/hour) for almost 85% of the days (including days with no rainfall) and only 10 days out of 365 had 30-min. rainfall intensities larger than 10 mm (= 20 mm/hour). The highest rainfall intensity was recorded on March 7, 1994, with 28.6 mm during the 30 minute period from 0:20 to 0:50 pm. On this day severe soil erosion, in terms of soil creep, was observed near Kilolo village.

**Table 4.4** - *Comparison between the frequency distribution for the total daily rainfall and the max. daily 30-min intensity rainfall for Muhu. The intensity data are extracted from the automatic rain gauge at the weather station.*

| Rainfall amounts (mm) | | No rainfall | 0.1-2 | 2-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-40 | 40-60 | > 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total daily rainfall** | % | 55.9 | 14.5 | 12.3 | 7.7 | 4.7 | 1.9 | 1.6 | 0.3 | 0.8 | 0.3 | 0 |
| | days | 204 | 53 | 45 | 28 | 17 | 7 | 6 | 1 | 3 | 1 | 0 |
| **Daily max. 30-min rainfall intensity** | % | 84.4 | | 8.2 | 4.7 | 1.1 | 0.3 | 0.5 | 0.8 | 0 | 0 | 0 |
| | days | 308 | | 30 | 17 | 4 | 1 | 2 | 3 | 0 | 0 | 0 |

The rainfall data will be discussed in details later in this chapter when discussing the differences in the hydrological response from each of the catchments.

## 4.2 Streamflow

Contrary to e.g. rainfall, streamflow can not be measured continuously. Instead the streamflow is measured indirectly through a continuous recording of the water-level at a specific selected site where, ideally, there is a unique relation between the water-level and the discharge. In order to establish this relation a number of simultaneous measurements of the water level and discharge have been carried out. After obtaining this relation between the water-level and the discharge (the Q-H-curve, (Q = discharge/ streamflow, H = water level) the measured water levels can be converted to discharge. Siltation and/or any other changes of the physical characteristics of the stream can result in a less unique relation between water level and discharge. Therefore the establishment of the rating curve will be given special attention regarding the quality of the streamflow data.

### 4.2.1 Collection and quality of water levels

As mentioned in section 3.3.1 there has been a continuous collection of water levels from automatic water level recorders in Mgera, Gendavaki and Muhu catchments. Data exist for the whole period since the start of the monitoring in March/April 1993 except from a few days because broken recorder pens. However, the number of missing days of records is less than 20 days for all the three stations in total. As all the missing days have occurred during periods with no rain it has been easy to determine the water levels during these days quite precisely by interpolation. Thus it have been possible, based on the water levels and the rating curves (see below), to establish daily streamflow values during the whole period for all stations.

### 4.2.2 Discharge measurements and establishing of rating curves (stage-discharge relation)

Since the start of the monitoring discharge measurements have been carried out from time to time with the highest frequency during the rainy season where a much wider range of and much quicker change in the water level is taking place. A list of all the discharge measurements carried out until mid November 1994 can be found in the data volume.

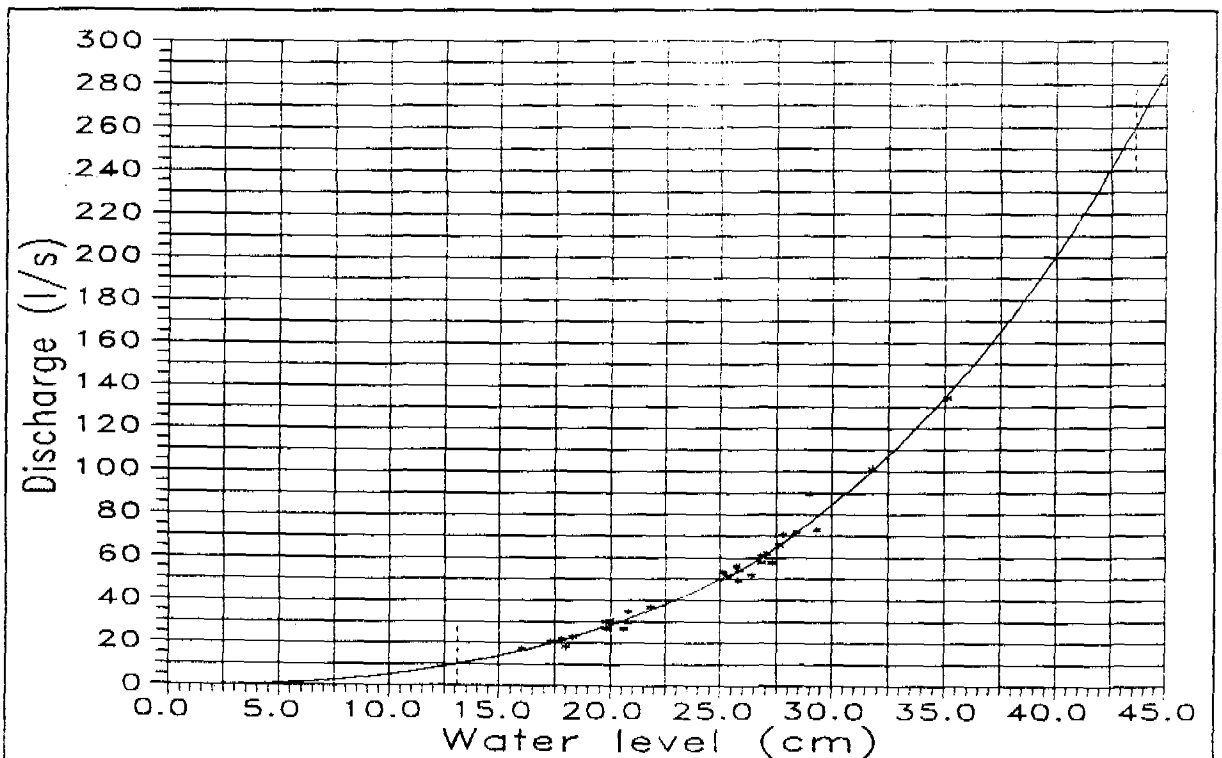


**Figure 4.5** - *The rating curve for Mgera. The two vertical dotted lines mark the lowest and the highest average daily water level recorded from April 1, 1993 to October 31, 1994.*

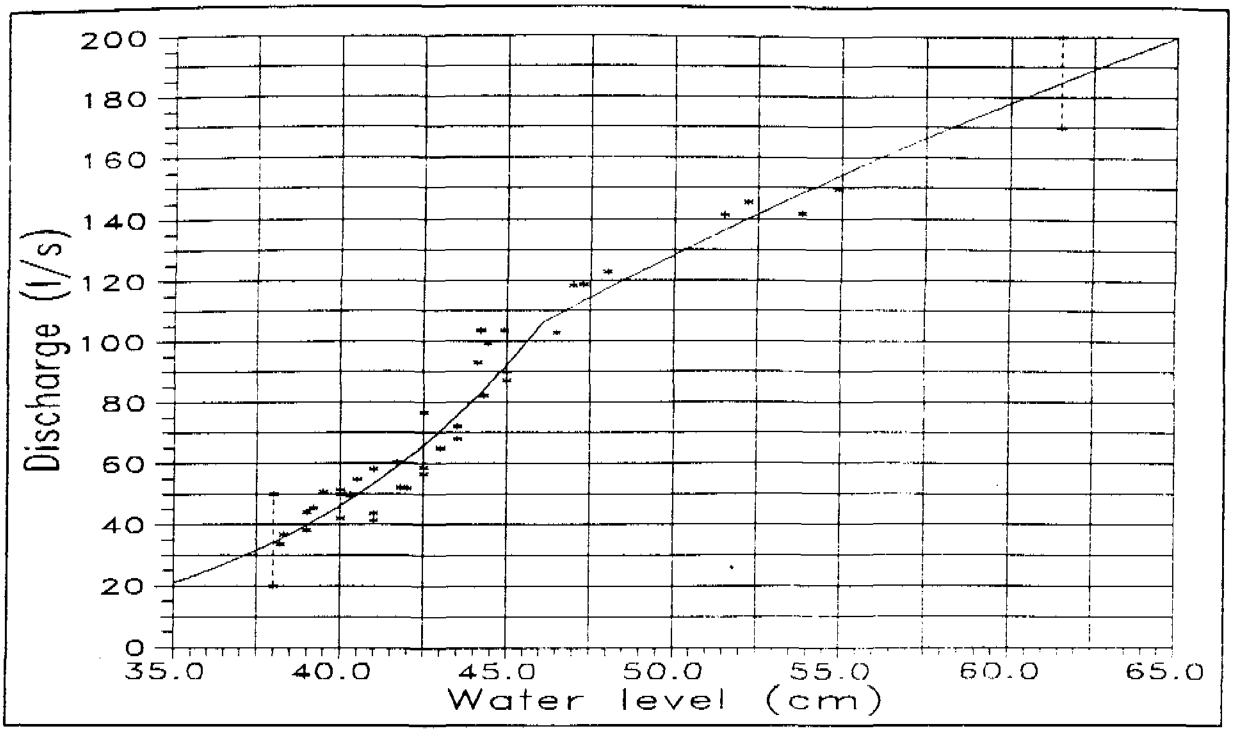


**Figure 4.6** - *The rating curve for Gendavaki. The two vertical dotted lines mark the lowest and the highest average daily water level recorded from April 1, 1993 to October 31, 1994.*

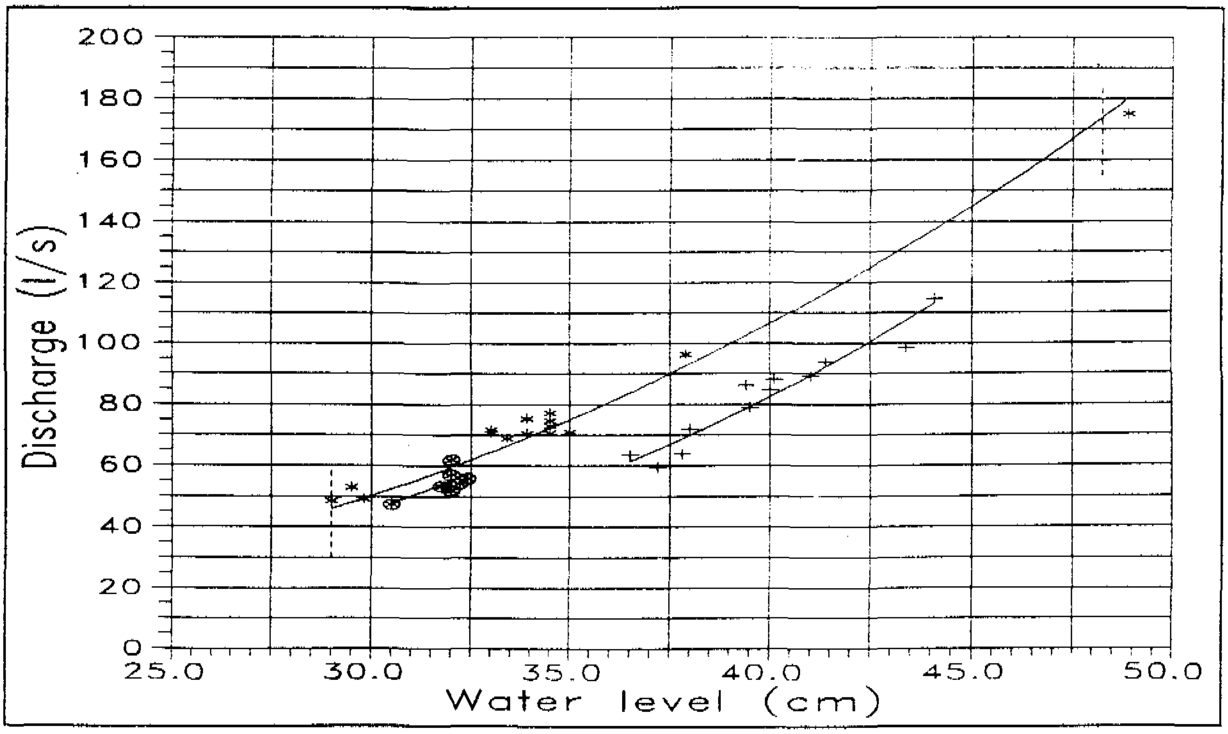


**Figure 4.7** - *The rating curve for Muhu. The curves represent the rating curves for different periods: +) 1.5 to 31.8 1993, ⊛) 1.9 1993 to 28.2 1994 and *) 1.1 to 31.10 1994 The two vertical dotted lines mark the lowest and the highest average daily water level recorded from April 1, 1993 to October 31, 1994.*

Based on the corresponding values of recorded water levels and calculated discharge during these measurements rating curves have been established for each of the catchments. The quality of the discharge measurements has been checked by making two subsequent discharge measurement with the same and with two different current meters respectively and the quality of the discharge measurements has been found to be very good.

In figures 4.5 to 4.7 are shown the established rating curve for Mgera, Gendavaki, and Muhu, respectively. These rating curves have been used to convert the water level recordings into the streamflow data presented later in this chapter.

A common problem concerning the establishment of rating curves is that often it is difficult to obtain discharge measurements for the very high water levels as they only occur very rarely and for a very short time during the heavy rainfall events. On the other hand, it is much easier to cover the lower water levels as there is very little change in the water levels during the dry season. Therefore the stage-discharge relation, and consequently the calculated discharge values are more reliable for lower than for higher water levels.

**Table 4.5** - *Comparison between recorded water levels and water levels during discharge measurements.*

| | MGERA | GENDAVAKI | MUHU |
|---|---|---|---|
| Lowest water level (cm) during discharge measurement | 16.0 | 38.2 | 29.0 |
| Lowest recorded daily average water level (cm) | 13.1 | 38.0 | 29.0 |
| Lowest recorded instantaneous water level (cm) | 13.1 | 38.0 | 29.0 |
| Highest water level (cm) during discharge measurement | 35.1 | 54.9 | 48.9 |
| Highest recorded daily average water level (cm) | 43.6 | 61.5 | 48.3 |
| Highest recorded instantaneous water level (cm) | 63.0 | 103.0 | 79 |
| Number of days where the daily *average* water level exceeds the highest water level during discharge measurements | 14 | 7 | 0 |

In Table 4.5 are shown the lowest and highest water levels for which discharge measurements have been carried out as well as the lowest and the highest *average daily* and *instantaneous* water levels, recorded during the period. The lowest and highest recorded daily average water levels are also indicated in figures 4.5 to 4.7 as dotted lines. The figures show that the lower part of the rating curves has been established from a large number of measurements, whereas the rating curves for the higher water levels are based on a few number of measurements. For some of the recorded water levels an extrapolation of the rating curve has been necessary as the recorded water levels are outside the range of water levels included in the discharge measurements.

Thus, when new discharge measurements covering the higher water levels are available, it might be necessary to adjust the rating curve and consequently the calculated discharge values. However, for all stations it is still on relatively few days where the average daily water level exceeds the range covered by the rating curves (although there are more days with instantaneous values outside this range). Therefore it is evaluated that a possible correction will only result in minor changes in the yearly runoff. However, the very high peak flow are still due to considerable uncertainty. On the other hand, it is assessed that the discharge for lower and medium-sized water levels is well determined with the present rating curves.

At Muhu the stage-discharge relation has been disturbed by siltation at the gauging site. Therefore it has been necessary to divide the discharge measurements into three groups based on the period they have been carried out. Thus one rating curve is based on discharge measurements from the start of the monitoring until August 31, 1993, a second curve covers discharge measurements from September 1, 1993 to February 28, 1994, while the third curve includes discharge measurements from March 1 to October 31, 1994. However, by doing so three relatively good rating curves have been established (see figure 4.7). After the problem was discovered in August 1993, a regular desilting of the site has been undertaken, which has solved the problem of the disturbance of the stage-discharge relation.

The streamflow data will be presented in the sections covering the respective catchments and discussed in details in section 4.5

## 4.3 Climatic data

Climatic data have been collected from the weather station at the school in Bomalang'ombe. As mentioned in section 3.3.1 the climatic station at Bomalang'ombe consists of: 1) An automatic weather station that records temperature, humidity, solar radiation, wind speed, and rainfall and 2) an evaporation pan (from which the evaporation from a free water surface can be calculated).

The parameters collected at the automatic weather station make it possible to calculate the potential evapotranspiration by using the Penman-formula. The data collected at the evaporation pan give an estimate of the evaporation from a free water surface. However, in the absence of climatic parameters data from evaporation pans have often been used to estimate of the potential evapotranspiration by multiplying the pan evaporation, $E_{pan}$, with a pan coefficient, $K_p$, which varies dependent on the climatic conditions. However, the use of the Penman-equation is widely accepted as being the more reliable estimate of the potential evapotranspiration and will therefore be used in the subsequent analysis.

Due to the high cost of a weather station and the possible problem by operating such a station in more remote area, no weather stations have been established in Mgera and Gendavaki. However, as the potential evaporation does not show the same local variations as e.g. rainfall, and as the catchments are close to each other (at least Muhu, Gendavaki and Ihaka) and are of the same physiographic nature (including altitude), it is believed that the records collected at Bomalang'ombe to a large extent also

**Table 4.6** - *Monthly mean values for climatic data collected at the weather station at the school in Bomalang'ombe in Muhu catchment.*

| Month | Mean Temperature (°C) | Mean Relative Humidity (%) | Mean Wind Speed (m/s) | Mean Radiation ($W/m^2$) | Total Rainfall (mm/ month) | Total Potential Evapotranspiration, $E_T$[d] (mm/ month) | Total Pan Evaporation, $E_{pan}$ (mm/ month) | Pan coefficient ($E_T/E_{pan}$)[d] |
|---|---|---|---|---|---|---|---|---|
| **Water year 1992-93 (partly):** | | | | | | | | |
| Apr-93 | 15.2 | 94.5 | 1.25 | 151.1 | 262.0 | 66[d]/70[d] | 71 | 0.92[d]/0.99[d] |
| May-93 | 14.3 | 91.7 | 1.04 | 165.1 | 62.0 | 68/72 | 70 | 0.97/1.03 |
| Jun-93 | 11.9 | 89.3 | 1.27 | 156.2 | 3.8 | 58/62 | 86 | 0.67/0.72 |
| Jul-93 | 10.6 | 88.0 | 1.51 | 158.9 | 13.0 | 60/64 | 72 | 0.83/0.89 |
| Aug-93 | | | | | 10.7[c] | 63/67[a] | 74 | 0.85/0.91 |
| Sep-93 | | | | | 10.2[c] | 83/89[a] | 117 | 0.71/0.76 |
| Oct-93 | | | | | 24.8[c] | 85/90[a] | 164 | 0.52/0.55 |
| **Water year 1993-94:** | | | | | | | | |
| Nov-93 | | | | | 41.1[c] | 97/103[a] | 149 | 0.65/0.69 |
| Dec-93 | | | | | 91.0[c] | 96/107[a] | 192[b] | 0.50/0.56 |
| Jan-94 | 16.9 | 89.8 | 1.09 | 199.1 | 182.2 | 97/103 | 129 | 0.75/0.80 |
| Feb-94 | 16.2 | 92.5 | 1.01 | 149.2 | 172.8 | 69/73 | 85 | 0.81/0.86 |
| Mar-94 | 16.1 | 94.6 | 0.66 | 169.1 | 340.0 | 80/85 | 104 | 0.76/0.82 |
| Apr.94 | 15.0 | 94.6 | 1.25 | 167.3 | 139.6 | 72/77 | 92 | 0.78/0.84 |
| May-94 | 13.6 | 95.1 | 1.35 | 117.4 | 154.0 | 52/55 | 67 | 0.78/0.84 |
| Jun-94 | 12.0 | 89.7 | 1.39 | 181.2 | 2.6 | 63/68 | 96 | 0.66/0.71 |
| Jul-94 | 11.7 | 90.5 | 1.56 | 141.0 | 9.2 | 57/60 | 84 | 0.68/0.71 |
| Aug-94 | 11.6 | 88.8 | 1.57 | 141.5 | 16.0 | 63/68 | 82 | 0.77/0.83 |
| Sep-94 | 12.9 | 84.9 | 1.75 | 188.7 | 9.2 | 83/89 | 86 | 0.97/1.03 |
| Oct-94 | 14.7 | 87.2 | 1.75 | 167.5 | 43.6 | 85/90 | 117 | 0.73/0.77 |
| **Water year 1994-95 (2 months):** | | | | | | | | |
| Nov-94 | 15.8 | 85.9 | 1.59 | 210.0 | 54.0 | 97/103 | | |
| Dec-94 | 16.3 | 91.6 | 1.49 | 200.1 | - | 101/107 | | |
| **Yearly (93-94) average** | **13.7** | **88.4** | **1.31** | **157.8** | | **76/82** | **107** | **0.71/0.77** |
| **Yearly (93-94) total** | | | | | **1199.9** | **914/978** | **1283** | |

a) 1994-value is used
b) This value seems unrealistically high
c) Values from the adjacent standard rain gauge are used.
d) The first number refer to the cultivated areas, whereas the second number refers to the forest at Mgera. The higher evaporation at the forest is due to the fact that the albedo (the reflection of short-wave radiation) is smaller for the forest.

cultivated land as well. Due to the late installation of the steel rods at Gendavaki, the results from Muhu and Mgera (where there are measurements for 2 dry seasons) will be emphasized.

It has been the plan to make soil moisture measurements at the end of each month. However, for a few month measurements have not been carried out as the technician doing the measurements has had other duties within the region.

Although the hydrological office has not been involved in soil moisture measurements prior to the start of the monitoring, the technician picked up the technique very fast, and the collection of soil moisture data has proceeded very smoothly. A few stolen steel rods have been replaced.

The quality of the data is in general considered to be very good, and there has been a good consistency between the two corresponding pair of steel rods for each depth. At the early start of the monitoring, Sokoine University of Agriculture (SUA), which at that time also used the TDR-instrument, compared the measured water contents by using the TDR-method with water contents determined by the gravity method and found a good correspondence. Such a check of the measurements will also be carried in connection with the forthcoming soil analyses in the catchments.

Presentation of the results:

In order to exemplify the soil moisture depletion during the dry season the soil moisture profiles for May, July and November for both the 1993 and 1994 dry seasons are shown in figures 4.9 and 4.10 for Mgera and in figures 4.11 and 4.12 for Muhu. For 1993 the soil moisture profiles cover the period May 30 to November 12, i.e. approximately 5½ month. For 1994 the profiles cover the period May 17 to November 24, i.e. approximately 6½ month. For both Mgera and Muhu the values comprise average values for both stations in the respective catchments.

**Table 4.8** - *Comparison between corresponding figures for soil moisture contents in 1993 and 1994.*

| | MGERA | | MUHU | |
|---|---|---|---|---|
| | 1993 | 1994 | 1993 | 1994 |
| Soil moisture content (mm) in May (0-1.25 m) | 309 | 339 | 353 | 399 |
| Soil moisture content (mm) in November (0-1.25 m) | 179 | 171 | 263 | 268 |
| Soil moisture content (mm) in May (1.25-2.65 m) | 387 | 400 | | |
| Soil moisture content (mm) in November (1.25-2.65 m) | 291 | 285 | | |

By comparing figures 4.9 and 4.10 and figures 4.11 and 4.12 it appears that the soil moisture profile patterns for 1993 are very similar to those for 1994. This appears even more clearly from Table 4.8

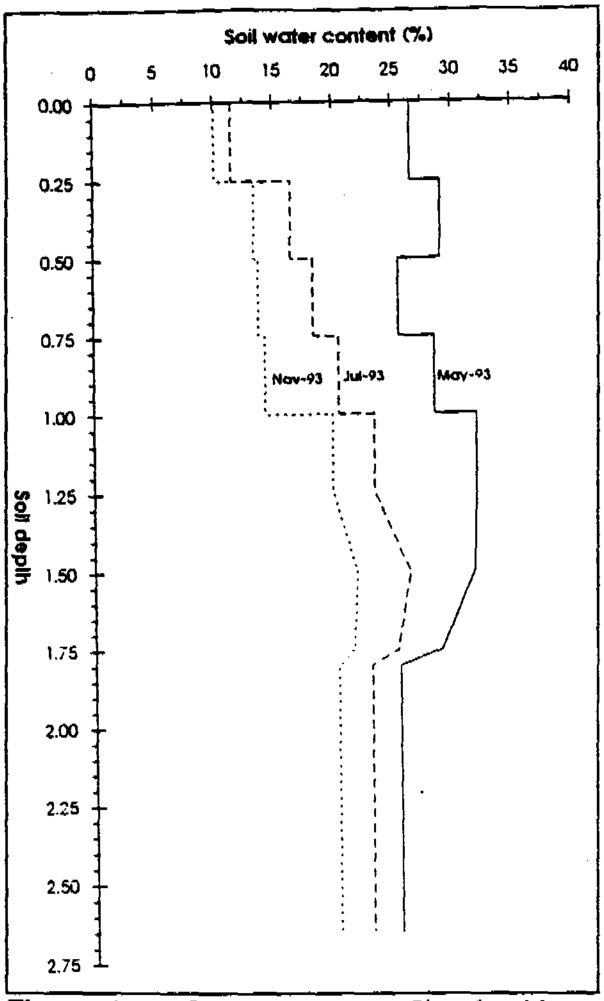


**Figure 4.9** - *Soil moisture profiles for Mgera during the dry season May - November 1993.*

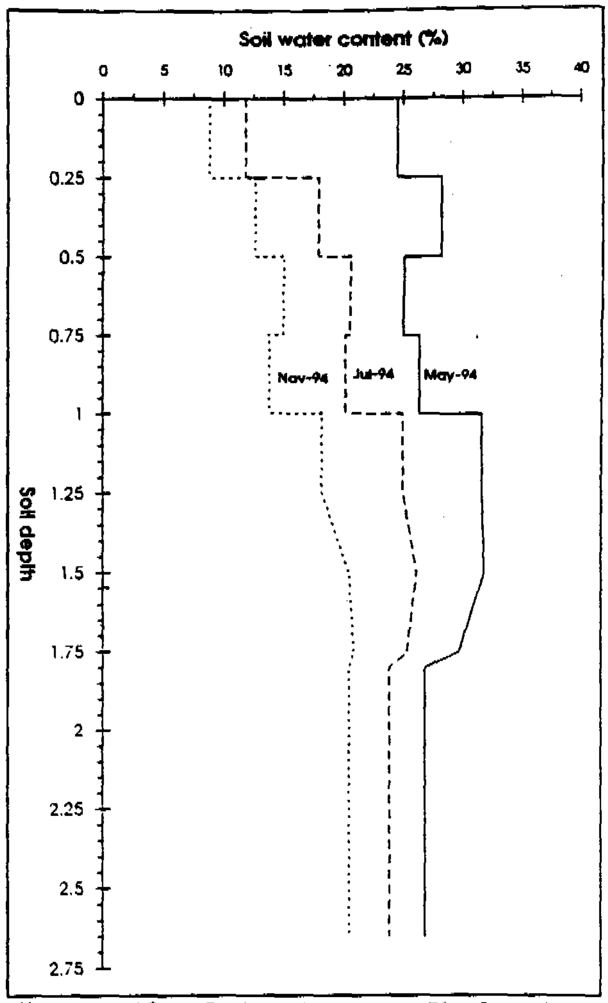


**Figure 4.10** - *Soil moisture profile for Mgera during the dry season May - November 1994.*

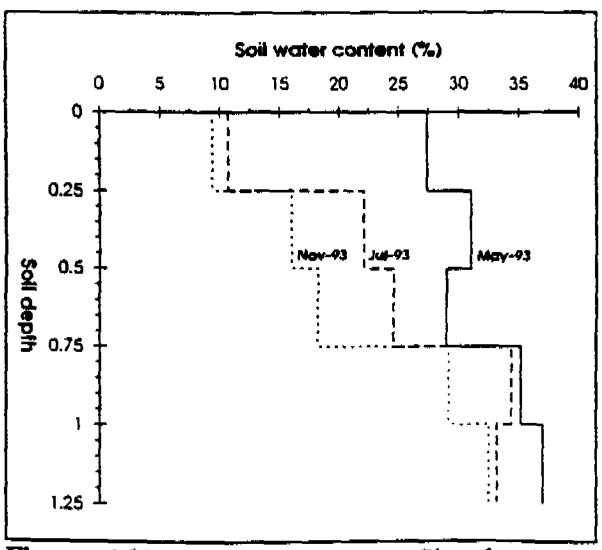


**Figure 4.11** - *Soil moisture profiles for Muhu during the dry season May - November 1993*

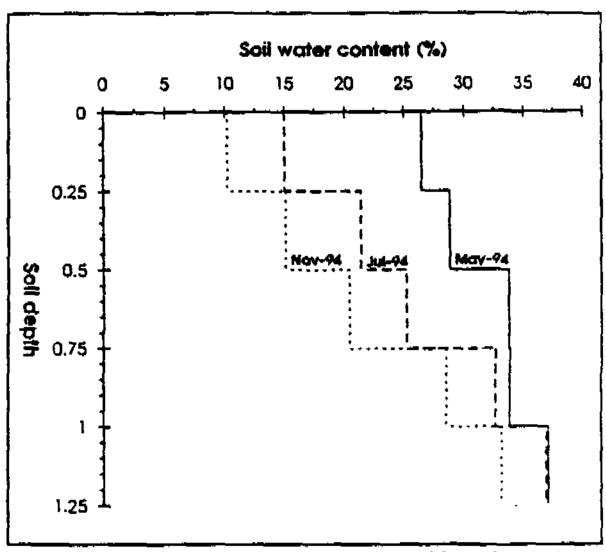


**Figure 4.12** - *Soil moisture profiles for Muhu during the dry season May - November 1994.*

where soil moisture contents from 1993 and 1994 are compared. Especially the soil moisture content at the end of the dry season (November) is very similar when 1993 is compared to 1994. The differences in soil moisture between May 1993 and May 1994 are believed to be due to heavy rain the days before the measurements in 1994.

From figures 4.9-4.12 is it also evident that the rate of soil moisture depletion is much higher in the beginning of the dry season when there is adequate soil moisture for the vegetation. For instance, although May-July only cover about 1/3 of the period shown (May-November), more than 50% of the depletion takes place during this period. The figures also show that the depletion takes place much faster at the upper soil layers, especially the upper 25 cm where almost all the depletion takes place between May and June. This is partly due to the fact that direct evaporation (through diffusion) takes place from the soil surface and partly to the fact that the highest root density is found in this part of the soil profile.

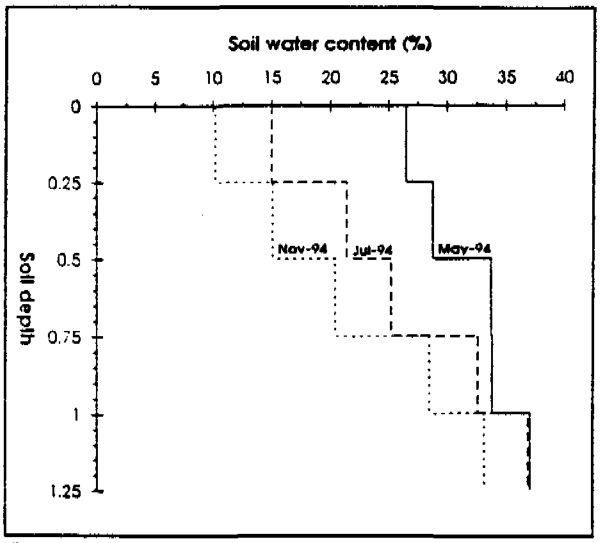


**Figure 4.13a** - *Soil moisture profile for Muhu during the dry season May - November 1994*

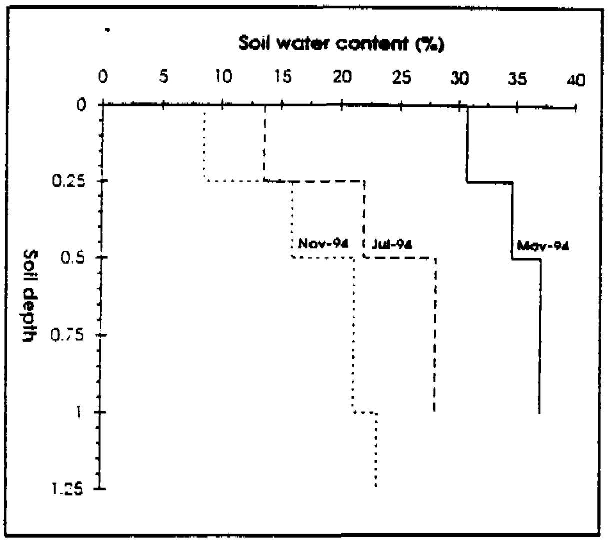


**Figure 4.13b** - *Soil moisture profiles for Gendavaki during the dry season May - November 1994.*

On the other hand there is a considerable difference between the profiles at Mgera and at Muhu. While there is a considerable soil moisture depletion for the entire upper 1.25 m in the forest at Mgera, the soil moisture depletion at Muhu falls abruptly below 0.75. For instance, both in November 1993 and November 1994 the soil moisture content at Muhu is more than 30% at between 1.00 and 1.25 m depth (while only 18-20% at Mgera) and 28-29% at between 0.75-1.00 m (while only 13-14% at Mgera). This surprisingly high soil moisture content in the maize fields in Muhu at the end of the dry season is probably due to the fact that there are very few roots below 0.75 m to extract the soil moisture, and thus the depletion can only take place via diffusion which is a very slowly process. As the depletion from 1.00-1.25 has been small it is believed that depletion below the measured depth of 1.25 m also will be small.

In Mgera, where the soil moisture has been measured to a depth of 2.65 m, there has been a considerable soil moisture depletion below 1.25 m and the profiles also indicate that a considerable soil moisture depletion may take place even below the measured depth of 2.65 m. However, the soil moisture from 1.80 to 2.65 m is an average value and it is thus difficult to assess how the true soil moisture profile should look in this interval.

However, a considerable soil moisture depletion can take place below 0.75 in a cultivated maize field. The soil moisture measurements from Gendavaki show a soil moisture depletion pattern that is quite different from those from the two soil moisture stations at Muhu. From figures 4.13a and 4.13b, where corresponding soil moisture profiles for Muhu and Gendavaki are shown for May, July and November 1994, it appears that the soil moisture depletion is similar for Gendavaki and Muhu regarding the upper 0.75 m, but, contrary to Muhu, there is also a considerable soil moisture depletion below 0.75 m at Gendavaki. This is somehow surprising, as the two soil moisture stations at Muhu show very little differences and had both very little depletion below 0.75 m. One of the explanations could be that the maize field at Gendavaki had been fallow for a number of years, and the field was severely infested with fern, and it is likely that the deep-rooted fern can be the main reason for the relatively high soil moisture depletion in Gendavaki as compared to Muhu. Furthermore, the very high soil moisture content below 0.50 m in May indicate that the soil moisture content is above field capacity. If so, part of the loss of soil moisture is due to free drainage rather than loss through evapotranspiration. When the field capacities are known (from the planned soil analyses) a more complete analysis of the soil moisture profiles can be made.

The differences between the soil moisture stations at Gendavaki and Muhu also clearly illustrate that the soil moisture data represent the conditions in the field where the stations are established and that there may be a considerable variation within the catchment even for the same type of vegetation due to differences in terms of management practice, location on the slope, soil type, etc.

## 4.5 Rainfall-runoff response

As it appears from section 3.2, the three catchments are very similar in terms of topography (slope steepness and altitude), geology, and catchment size and shape. Furthermore the rainfall data presented in section 4.1 have shown that the catchments, at least for the 1993-94 water year, are also very similar in terms of total yearly rainfall amount, the frequency of the daily rainfall amounts as well as the temporal distribution. This highly facilitates a comparison between the impact of the different types of land use on the hydrological regime.

In Table 4.9 are shown the corresponding monthly values for rainfall and runoff for Mgera, Gendavaki and Muhu. The daily values for rainfall and runoff for all three catchments are shown in figures 4.14 to figure 4.19.

From the corresponding figures showing rainfall and runoff for each of the catchments it can be seen that there is a very good consistency between the rainfall events and the temporal increase and decrease in daily runoff. In the beginning of the monitoring it was feared that rises and falls in water-levels during the dry season were due to inaccuracy of the instruments. However, from the corresponding rainfall and runoff figures it can clearly be seen that these rises are caused by minor rainfall events during the dry season. The good correspondence also support the earlier assessment of good quality rainfall and discharge data.

**Table 4.9** - *Corresponding monthly values of rainfall and runoff for Mgera, Gendavaki, and Muhu from 1.4.93 to 31.10.94.*

| MONTH | MUHU | | GENDAVAKI | | MGERA | |
|---|---|---|---|---|---|---|
| | Rainfall (mm) | Runoff | Rainfall (mm) | Runoff | Rainfall (mm) | Runoff |
| Nov-93 | | | | | 188[b] | |
| Dec-93 | 55[a] | | 55[a] | | 23[b] | |
| Jan-93 | 53[a] | | 53[a] | | 65[b] | |
| Feb-93 | 203[a] | | 203[a] | | 126[b] | |
| Mar-93 | 161[c] | | 161[c] | | 178[b] | |
| Apr-93 | 254.2 | | 301.3 | 50.2 | 247.5 | 46.2 |
| May-93 | 60.2 | 37.5 | 68.9 | 39.4 | 48.4 | 29.7 |
| Jun-93 | 5.6 | 30.3[d] | 13.0 | 27.9 | 4.7 | 17.7 |
| Jul-93 | 6.1 | 32.6[d] | 14.9 | 27.4 | 14.5 | 17.4 |
| Aug-93 | 8.4 | 30.4[d] | 10.2 | 25.1 | 4.7 | 15.0 |
| Sep-93 | 7.8 | 26.3 | 6.1 | 22.3 | 3.2 | 11.9 |
| Oct-93 | 21.9 | 27.1 | 30.1 | 20.3 | 11.6 | 10.5 |
| **Total Apr-93 to Oct-93** | **837** | **184[f]** | **916** | **213[f]** | **912[e]** | **148[f]** |
| Nov-93 | 32.8 | 27.9 | 32.8 | 19.2 | 16.9 | 8.7 |
| Dec-93 | 83.7 | 29.3 | 144.8 | 24.4 | 25.7 | 7.4 |
| Jan-94 | 197.6 | 32.3 | 173.2 | 29.4 | 231.4 | 20.6 |
| Feb-94 | 173.9 | 31.6 | 268.4 | 39.8 | 323.5 | 35.9 |
| Mar-94 | 320.7 | 53.2 | 189.6 | 48.8 | 377.2 | 61.1 |
| Apr-94 | 134.6 | 38.4 | 171.1 | 40.2 | 120.1 | 35.2 |
| May-94 | 129.9 | 40.8 | 169.4 | 49.6 | 121.8 | 37.4 |
| Jun-94 | 0.0 | 30.3 | 1.2 | 33.9 | 2.7 | 21.3 |
| Jul-94 | 5.3 | 29.3 | 5.3 | 31.2 | 6.4 | 18.6 |
| Aug-94 | 13.0 | 27.3 | 16.1 | 28.2 | 5.4 | 17.0 |
| Sep-94 | 4.7 | 25.6 | 5.4 | 23.2 | 1.5 | 13.8 |
| Oct-94 | 32.2 | 26.6 | 54.5 | 29.5 | 24.4 | 13.4 |
| **Total Nov 93 Oct 94** | **1,128** | **393** | **1,231** | **397** | **1,257** | **290** |

a) Readings by the Agric Unit at the school at Bomalang'ombe, the values are used for both Muhu and Gendavaki
b) Readings from the automatic rain gauge established by SUA at Mgera site
c) Readings partly by the Agric Unit at the school at Bomalang'ombe and partly from the WRM rain gauges
d) Due to siltation of the station during this period, the actual discharge measurements during this period has been used to estimate the runoff
e) Notice that Mgera contains one more month (November 1992) of rainfall records than the other stations
f) Notice that Mgera and Gendavaki contain one more month of runoff records than Muhu

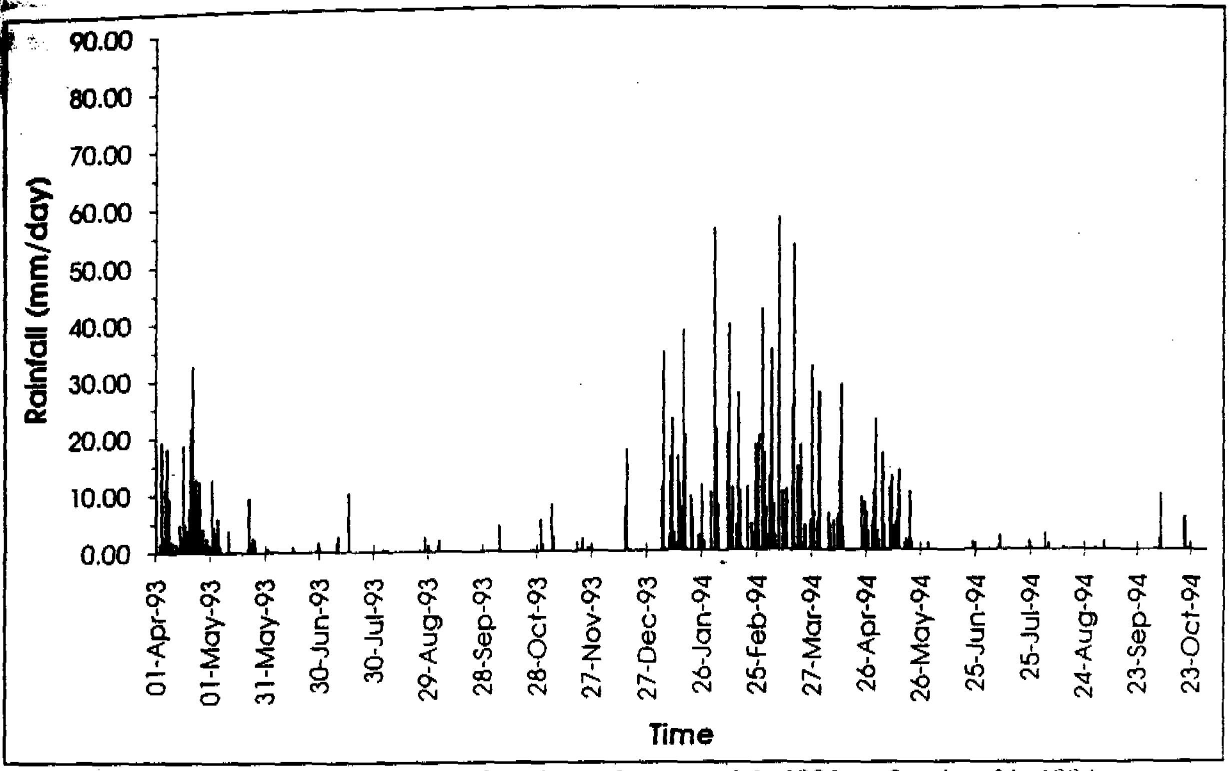


**Figure 4.14** - *Daily rainfall (mm/day) for Mgera from April 1, 1993 to October 31, 1994.*

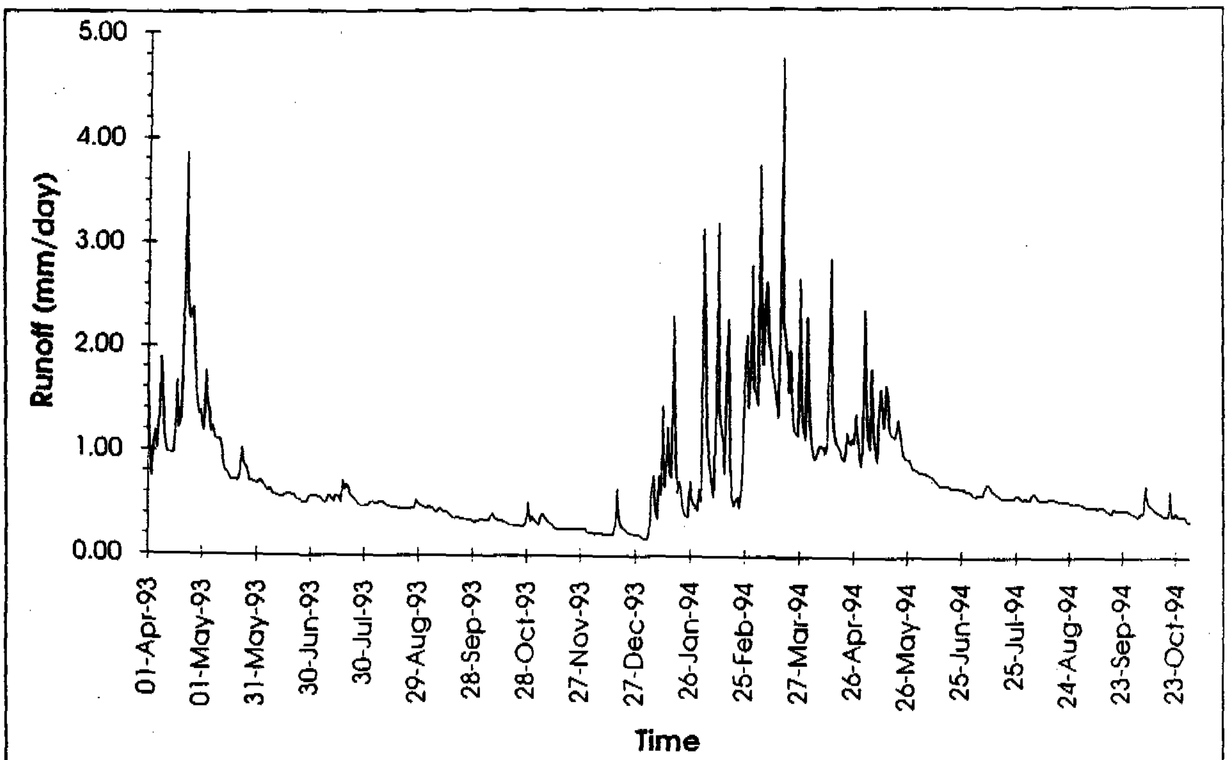


**Figure 4.15** - *Daily runoff (mm/day) for Mgera from April 1, 1993 to October 31, 1994.*

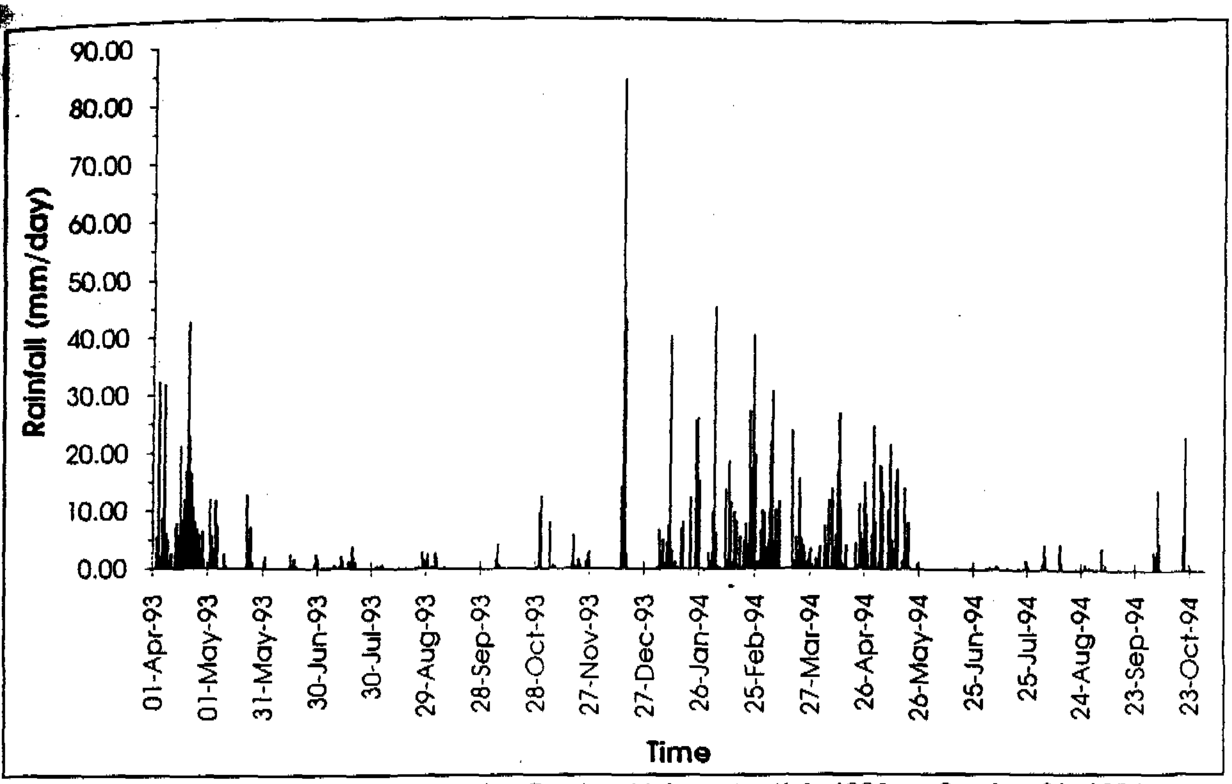


**Figure 4.16** - *Daily rainfall (mm/day) for Gendavaki from April 1, 1993 to October 31, 1994.*

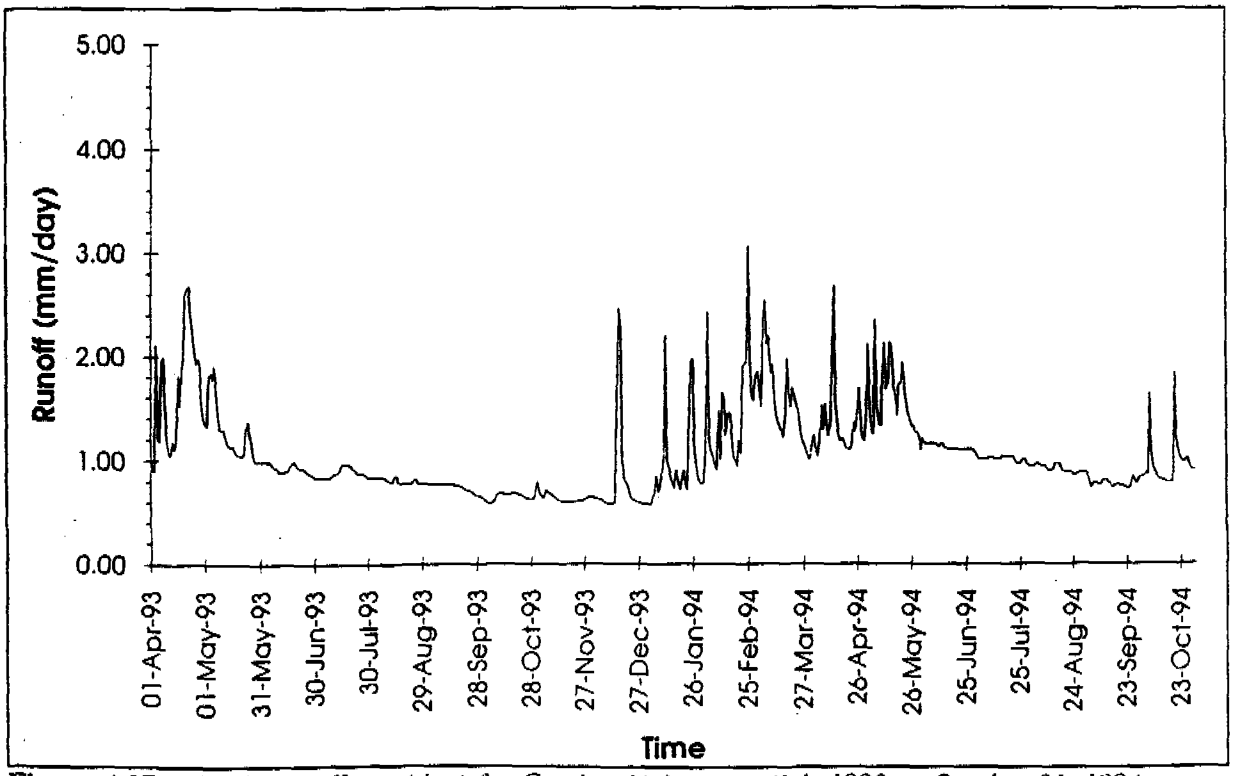


**Figure 4.17** - *Daily runoff (mm/day) for Gendavaki from April 1, 1993 to October 31, 1994.*

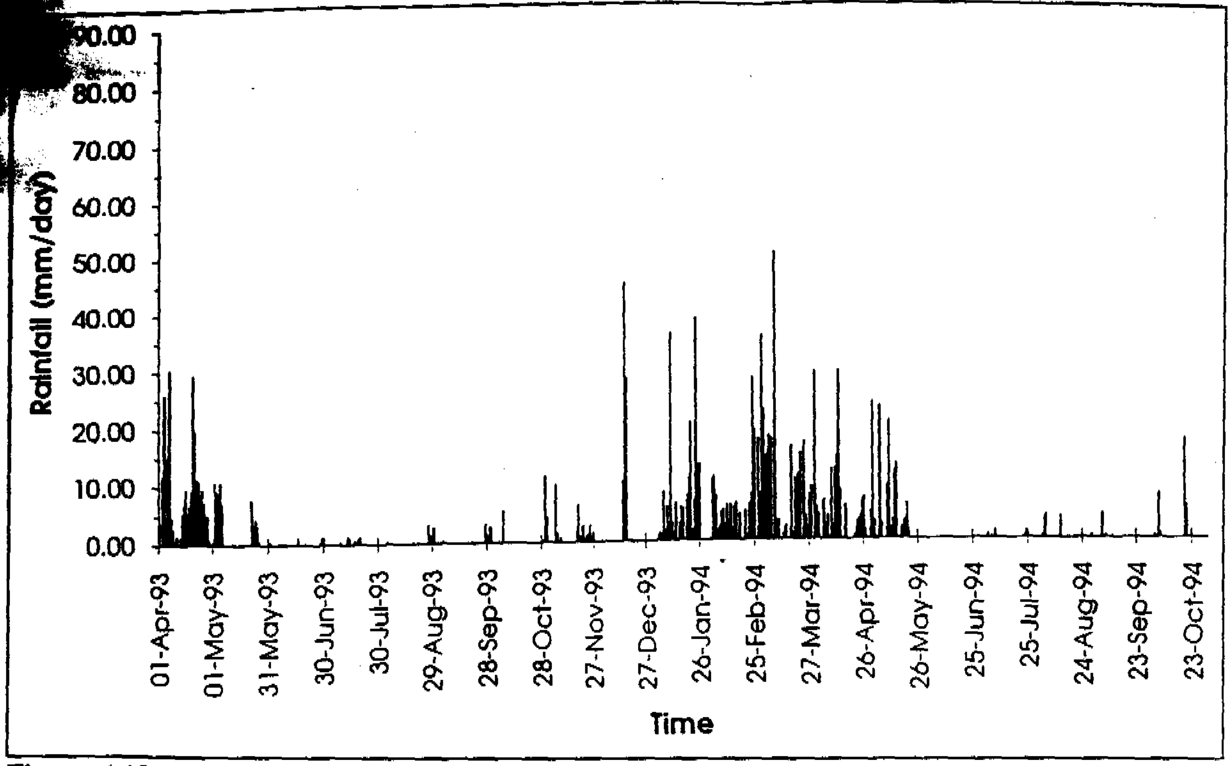


**Figure 4.18** - *Daily rainfall (mm/day) for Muhu from April 1, 1993 to October 31, 1994.*

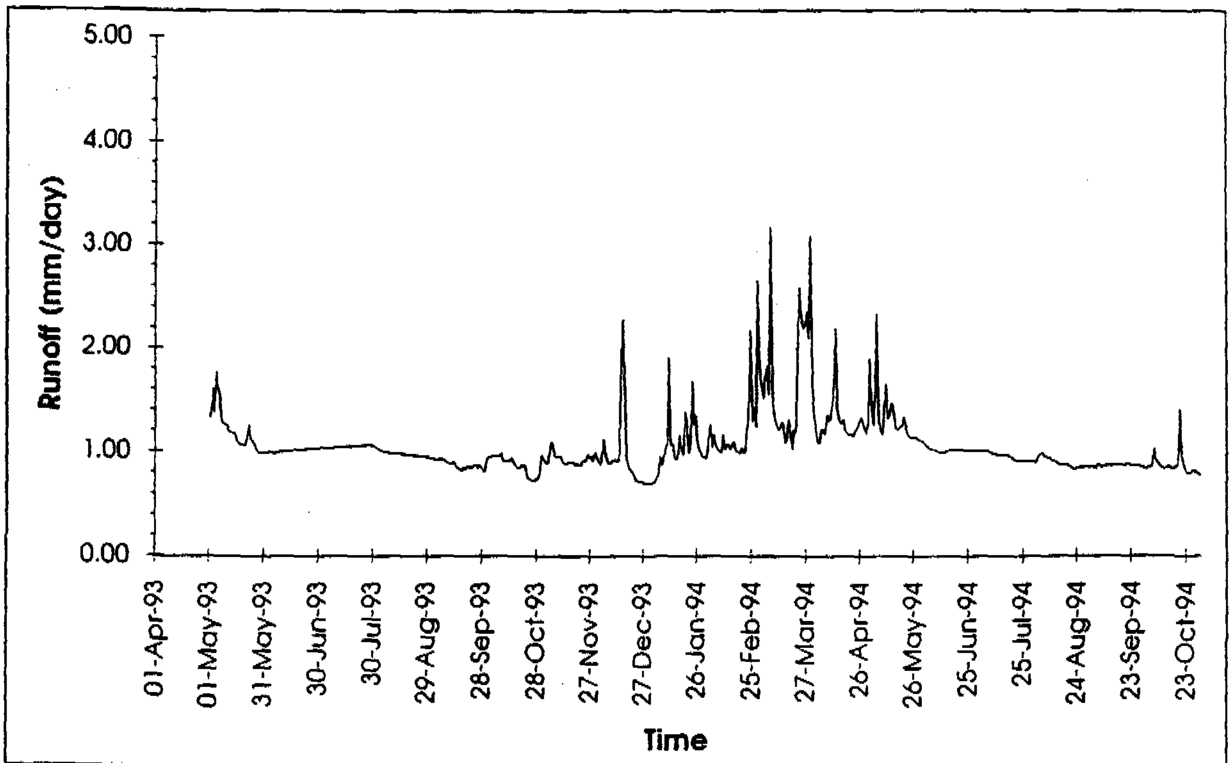


**Figure 4.19** - *Daily runoff (mm/day) for Muhu from May 1, 1993 to October 31, 1994.*

## 4.6 Discussion of the impact of the land use practice on the water resources

The preceding sections have contained a presentation of data, how they have been derived, their reliability, etc. In this section we will try to relate the hydrological observations and the environment in the three catchments, i.e. to discuss the impact of the different types of land use (represented by the three catchments) on the water resources, quantitatively.

The discussion will include the following three hydrological aspects:

1) Establishment of yearly water balances
2) Low flows by the end of the dry season
3) Hydrological response during heavy rains (flood flows)

### 4.6.1 Yearly water balance

The yearly water balance is an important tool when analyzing the response from a certain catchment as it tells how large a part of the rainfall that ends up in the river and how large a part of the rainfall that evapotranspirated from the catchment, either through direct evaporation from the soil or water surfaces or through transpiration via the vegetation.

For a river catchment the yearly water balance (in mm) can be represented by the following equation:

$$P = Q + E_a + \Delta M + \Delta G \qquad \text{(Eq. 4.1)}$$

where

| | |
|---|---|
| $P$ | = Rainfall |
| $Q$ | = Runoff |
| $E_a$ | = Actual evapotranspiration |
| $\Delta M$ | = Change of soil moisture storage |
| $\Delta G$ | = Change of ground water storage |

From equation 4.1 it follows that the actual evapotranspiration, $E_a$, can be determined as:

$$E_a = P - Q - \Delta M - \Delta G \qquad \text{(Eq. 4.2)}$$

When the water balance is based on a number of years, eq. 4.1 can usually be simplified as follows:

$$P = Q + E_a \qquad \text{(Eq. 4.3)}$$

as the average yearly changes of ground water and soil moisture storage becomes insignificant. Even within single water years the changes of both the soil moisture storage and ground water storage will often be small, due to the nature of the water year as it runs from the end of one dry season to the end of another dry season. However, in the following estimations of the water balances for each of the catchments both soil moisture storage and ground water storage will be accounted for.

An estimate of the change of soil moisture storage can be obtained by considering the soil moisture content at the beginning and at the end of the water year. Unfortunately October 1993 and October 1994 are some of the few months for which no soil moisture measurements were made by the end of the month. Thus soil moisture measurements from November 12, 1993 and November 24, 1994 have been used to estimate the soil moisture content at the beginning and at the end of the water year taking into consideration the amount of rainfall that occurred from 1 to 12 of November 1993 and October 31 to November 24, 1994. The estimated soil moisture content at the beginning and the end of the water year and the resulting change of soil moisture for each of the catchments are presented in Table 4.10.

**Table 4.10** - *Estimated changes of soil moisture content for the water year 1993-94, based on soil moisture content at the beginning and at the end of the water year.*

| | MGERA[a] | GENDAVAKI[b] | MUHU[c] |
|---|---|---|---|
| Estimated soil moisture content (mm) at the beginning of the water year | 470 | 145 | 262 |
| Estimated soil moisture content (mm) at the end of the water year | 467 | 149 | 273 |
| **Estimated change of soil moisture storage for the 1993-94 water year** | **- 3[a]** | **+ 4[b]** | **+ 11[c]** |

a) Includes the upper 2.65 m  b) Includes the upper 1.00 m  c) Includes the upper 1.25 m

The figures for the changes of soil moisture content given in Table 4.10 only include the part of the unsaturated zone for which soil measurements are carried out, i.e. the upper 2.65 m in Mgera, the upper 1,00 m in Gendavaki and the upper 1.25 m in Muhu. However, as the changes are very small and the changes in soil moisture normally will be most significant at the upper soil layer, the changes of soil moisture storage below the measured depths can be considered insignificant.

**Table 4.11** - *Estimated ground water storage for the water year 1993-94, based on the baseflow at the beginning and at the end of the water year and the calculated recession constant of baseflow for the dry season (June-October 1994).*

| | **MGERA** | **GENDAVAKI** | **MUHU** |
|---|---|---|---|
| Baseflow (mm/day) November 1, 1993 | 0.32 | 0.635 | 0.775 |
| Baseflow (mm/day) October 31, 1994 | 0.36 | 0.740 | 0.790 |
| Recession constant for the baseflow ($k_{res}$) (day$^{-1}$) | - 0.004216 | - 0.003954 | - 0.001486 |
| **Estimated changes in groundwater storage (mm)** | **+ 10** | **+ 27** | **+ 10** |

...s the baseflow (the part of the streamflow that originates from the ground water) to a large extent ...etermined by the ground water levels, the changes of ground water storage within the water year ...n be considered small if the baseflows at the beginning and at the end of the water year are similar.

In Table 4.11 are presented the estimated baseflows for each of the three catchments at the beginning and at the end of the water year. The corresponding flows at the beginning and the end of the water year are within the same order of magnitude for all the catchments. Based on the differences in baseflow and the recession constant for the baseflow, $k_{res}$, the estimated changes in ground water storages have been calculated. As it can be seen from the bottom of Table 4.11, changes in ground water storages are minor compared to the total yearly rainfall.

When P, Q, ΔM and ΔS are estimated, the yearly actual evapotranspiration is determined from equation 4.2. Hence, the total yearly water balance has been established. All the components of the water balance for each of the catchments are presented in Table 4.12 together with some other important hydrological key figures.

**Table 4.12** - *Yearly water balance in mm for 1993-94 for Mgera, Gendavaki and Muhu catchments.*

| | MGERA | GENDAVAKI | MUHU |
|---|---|---|---|
| **Water balance components:** | | | |
| Rainfall (P) | 1257 | 1232 | 1131 |
| Runoff (Q) | 290 | 397 | 393 |
| Soil moisture storage | ≈ - 3 | ≈ + 4 | ≈ + 11 |
| Ground water storage | ≈ + 10 | ≈ + 27 | ≈ + 10 |
| Actual evaporation, $E_a$ | 960 | 804 | 717 |
| **Other key figures:** | | | |
| Potential evaporation, $E_p$ | 978 | 914 | 914 |
| $E_a$ / $E_p$ | 0.98 | 0.88 | 0.78 |
| Runoff coefficient (Q/P) | 0.23 | 0.32 | 0.35 |
| Minimum specific low flow (l/s/km$^2$) | 3.3 | 7.5 | 8.6 |

From Table 4.12 it can be seen that the yearly runoff from the two cultivated catchments, Gendavaki and Muhu, are very similar, 397 mm and 393 mm respectively, whereas the yearly runoff from the forested Mgera catchment is considerably lower, namely only 290 mm. Thus, although Mgera has received the highest amount of rainfall (the rainfall at Gendavaki is only slightly lower though) the total yearly runoff from the forested catchment is more than 25% lower than the yearly runoff from both of the cultivated catchments. This also appears from the runoff coefficients (the yearly runoff as the percentage of the yearly rainfall) which is only 25% for Mgera while it is 32% and 35% for Gendavaki and Muhu, respectively.

...might expect that the higher yearly runoff from the cultivated catchments would be caused by a ...direct surface runoff during heavy rains. It is believed by many that cultivation on steep slopes ...ays results in a substantial decrease in the infiltration rate and consequently an increase in the ...urface runoff - a statement I have often been confronted with among HIMA staff and government staff in the region in general.

**Table 4.13** - *Distribution of yearly runoff between wet season and dry season flow for the 1993-94 water year.*

| Catchment | Total yearly runoff | | Wet season (Dec-May) runoff | | Dry season (Jun-Nov) runoff | |
|---|---|---|---|---|---|---|
| | mm | % | mm | % | mm | % |
| Mgera | 290 | 100 | 197 | 68 | 93 | 32 |
| Gendavaki | 397 | 100 | 232 | 58 | 165 | 42 |
| Muhu | 393 | 100 | 226 | 58 | 167 | 42 |

However, when analyzing the runoff patterns by dividing the yearly runoff into runoff during the dry season (which is mainly baseflow and hardly consists of any surface runoff) and the wet season it appears very clearly (see Table 4.13) that the lower yearly runoff from the forested catchment mainly is due to a much lower dry season flow from this catchment rather than a very high runoff from the cultivated catchments during the wet season. The wet season flows from the cultivated catchments are only about 16% higher than from the forested catchment while the dry season flow is 78% higher from the cultivated catchments as compared to the forested catchment. Thus, the dry season flow contributes with 42% of the total yearly runoff from the cultivated catchments while it only makes up 32% of the total yearly runoff in the forested catchment.

This indicates very clearly that the groundwater recharge in the forested catchment has been much lower than in the cultivated catchments - actually only about 50-60% of the groundwater recharge in the cultivated catchments, and this despite the fact that the total yearly rainfall in Mgera is more than 100 mm higher than in Muhu.

The groundwater recharge, $Q_g$, is equal to the amount of water infiltrating through the soil surface, $Q_{inf}$, minus the amount of water which is lost through evapotranspiration $E_a$ (mainly due to transpiration through the vegetation):

$$Q_g = Q_{inf} - E_a \qquad \text{(Eq. 4.3)}$$

Thus, the lower ground water recharge in Mgera may either be due to less water infiltrating through the soil surface in the forest or due to a higher evapotranspiration from the forest. It is generally accepted that the infiltration capacity of a soil of a natural dense evergreen forest in general is higher compared to a soil on a similar cultivated field. Furthermore, the good ground cover also favour that a large proportion of the rainfall will infiltrate. Measurements of the saturated hydraulic conductivity of the topsoils in Mgera and Muhu confirm this. It was found that the saturated hydraulic conductivity

Mgera was twice as high as that of Muhu, i.e. $15 \cdot 10^{-5}$ m/s and $7.7 \cdot 10^{-5}$ m/s, respectively, (Krogh, 992).

Thus the reason for the much lower ground water recharge in the forest catchment must be due to the higher actual evapotranspiration, i.e. higher water consumption by the forested catchment compared to the cultivated catchments.

**Table 4.14** - *Calculation of actual evaporation during the dry season from soil moisture depletion and taking into the consideration the corresponding rainfall during the dry season.*

| | MUHU I (Ibumila) | MUHU II (Muhu River) | MUHU (average) | MGERA (Boundary) | MGERA (Panel) | MGERA (Average) |
|---|---|---|---|---|---|---|
| May 30, 1993 | 334.7 | 372.1 | 353.4 | 311.4 | 308.2 | 309.8 |
| November 12, 1993 | 240.7 | 285.9 | 263.3. | 165.5 | 192.3 | 178.9 |
| Rainfall 30.5 - 12.11 | 63.6 | 53.1 | 58.4 | 49.9 | 49.9 | 49.9 |
| Soil moisture depletion in the upper 1.25 m due to evapotranspiration | 157.6 | 139.3 | 148.5 | 195.8 | 165.8 | 180.8 |
| Soil moisture depletion below 1.25 (in forest) | | | | 96.4 | 96.4 | 111.4 |
| **Total soil moisture depletion due to evapotranspiration** | **157.6** | **139.3** | **148.5** | **292.2** | **262.2** | **292.2** |
| May 17, 1994 | 372.6 | 426.5 | 399.6 | 341.0 | 338.2 | 339.6 |
| November 24, 1994 | 236.0 | 300.0 | 268.0 | 164.1 | 177.7 | 170.9 |
| Rainfall 17.5 - 24.11 | 95.6 | 80.8 | 88.2 | 69.7 | 69.7 | 69.7 |
| Soil moisture depletion in the upper 1.25 m due to evapotranspiration | 232.2 | 207.3 | 219.8 | 246.6 | 230.2 | 238.4 |
| Soil moisture depletion below 1.25 m down to 3.25 m (in forest) | | | | 114.7 | 114.7 | 129.7 |
| **Soil moisture depletion due to evapotranspiration** | **232.2** | **207.3** | **219.8** | **361.3** | **344.9** | **368.1** |

From Table 4.12 it can also be seen that the actual evapotranspiration, as determined from the water balance, is much higher from the forested catchment (Mgera) when compared to the cultivated catchments. It is approximately 240 mm higher than at Muhu and 150 mm higher than at Gendavaki.

Based on the measured soil moisture depletion and rainfall, the actual evapotranspiration during the dry seasons 1993 and 1994 has been estimated for Mgera and Muhu in Table 4.14. From Table 4.14 (which corresponds to the soil moisture profiles in figures 4.9 to 4.12) it is evident that the actual evapotranspiration at Mgera is much higher than at Muhu, mainly due to the existence of a permanent vegetation with deeper roots than the maize resulting in soil moisture depletion to a greater depth. However, it should be kept in mind that the soil moisture measurements only represent the conditions in a smaller part of the catchments. The comparison between the soil moisture profiles for Gendavaki and Muhu in figure 4.13a and 4.13b indicates that the soil moisture depletion from cultivated land may be higher than the figures presented in Table 4.14.

During the rainy season the evapotranspiration is also expected to be higher from the forested catchment than from the cultivated catchments, because the albedo is lower for an evergreen forest than for a maize field or bare soil. This is the reason for giving two sets of figures for potential evapotranspiration in Table 4.6 - one set for cultivated land and one set for an evergreen forest. Furthermore, during the rainy season the actual evapotranspiration for the forested catchment may even be higher than the potential evapotranspiration as part of the rainfall will be intercepted and evaporate from the canopy and therefore never reach the soil surface.

**Table 4.15** - *Comparison between $E_a$ estimated from a) the water balance and b) soil moisture measurements and the potential evaporation (measured at the weather station).*

| PERIOD | MGERA | GENDAVAKI | MUHU |
|---|---|---|---|
| $E_a$ 1.11 to 9.12 1993 (from soil moisture measurements) | 59 | 39 | 28 |
| $E_a$ 9.12.93 to 16.5.94 (determined from the potential evapotranspiration during this period, $E_a = E_p$) | 434 | 414 | 414 |
| $E_a$ 17.5 to 31.10 1994 (from soil moisture measurements) | 368 | 333 | 220 |
| $E_a$ 1993-94 as (determined from soil moisture measurements and potential evaporation) | 861 | 786 | 662 |
| $E_a$ 1993-94 (from water balance) | 960 | 804 | 717 |
| **Difference between $E_a$ determined from the water balance and $E_a$ determined from soil moisture measurements** | **99** | **18** | **55** |
| | **10%** | **2%** | **8%** |

In Table 4.12 the actual yearly evaporation was obtained by subtracting the runoff, the change of groundwater, and the change of the soil moisture storage from the rainfall. I Table 4.15 an attempt has been made to make a <u>rough</u> estimate of the actual evapotranspiration independently of the other components of the water balance. Instead the soil moisture measurements are used to estimate the actual evapotranspiration during the dry part of the water year, assuming that the actual evaporation is equal to the soil moisture depletion. This value is due to some uncertainty as it is difficult to estimate the soil moisture depletion taking place below the measured depth and because the soil moisture measurements not necessarily are representative for the whole catchment. The potential evaporation has been used to estimate the actual evaporation during the wet part of the water year assuming that $E_a = E_p$.

For Gendavaki there is a good correspondence between $E_a$, as determined from the two methods, whereas there is a difference of 8-10% for Mgera and Muhu. However, this is not larger deviations than normally experienced in evaporation studies. The underestimation at Mgera is mainly thought to be due to the fact that interception and subsequent evaporation from the canopy (as discussed above) have not been taken into consideration. It is not unlikely that this effect will result in an additional 50 to 75 mm evaporation during the rainy season. Also, the actual evapotranspiration during the dry season may be higher as the soil moisture depletion below the depth for which we have been measuring is underestimated. Furthermore, some exfiltration may take place in the lower parts of the catchment during the dry season as discussed later in section 4.6.2. However, both methods come to the result that the evapotranspiration is substantial higher from the forested catchment compared to the cultivated catchments.

### 4.6.2 Low flow

The low flow indicates the lowest measured discharge (or streamflow) by the end of the dry season. As the monitoring started late March 1993, the data until now include two dry seasons and thereby low flow values for two seasons. Furthermore, discharge measurements were carried out in Muhu and Gendavaki during the establishment of the stream gauging stations in November/December 1992, which gives good estimates for the low flow for the 1991-92 water year. The specific low flow indicates the lowest flow recorded in terms of flow per km$^2$. Thus, the specific low flow is a more relevant figure when comparing catchments of different sizes.

**Table 4.16** - *Specific low flow for 1991/92, 1992/93 and 1993/94*

| Catchment | 1991/92 | | | 1992/93 | | | 1993/94 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Date | Low flow | Specific low flow | Date | Low flow | Specific low flow | Date | Low flow | Specific low flow |
| | | l/s | l/s/km$^2$ | | l/s | l/s/km$^2$ | | l/s | l/s/km$^2$ |
| MUHU | 26.11.92 | 48.7[a] | 9.5[a] | 31.12.94 | 41.3 | 8.0 | 21.11.94 | 44.3 | 8.6 |
| GENDAVAKI | 2.12.92 | 42.1[a] | 8.2[a] | 2.1.94 | 34.3 | 6.7 | 27.11.94 | 38.7 | 7.5 |
| MGERA | - | - | - | 1.1.94 | 10.1 | 2.0 | 24.11.94 | 17.2 | 3.3 |
| IHAKA | - | - | - | 10.12.93 | 55.0[a] | 10.9[a] | 1.12.94 | 50.3[a] | 10.0[a] |

a) These are estimated low flow / specific low flow values based on discharge measurements at the end of the dry season

While the total yearly runoff and the runoff during the rainy season mainly may be important in relation to downstream users (e.g. hydropower production and irrigation) the magnitude of the low flow

... the streamflow during the dry season in general is important for the people living in or in the ...ity of the catchments as the water from the stream are the source of water for domestic use.

...ow flow values for the 1992-93 and the 1993-94 water years as well as the estimates for the 1991-92 water year are presented in Table 4.16.

While the total runoff during the dry month was 78% higher from the cultivated catchments than from the forested Mgera catchment (cf. Table 4.13) the specific low flows for Muhu and Gendavaki are more than 300 and 260% higher than those from Mgera, as average for 1992/93 and 1993/94. As discussed in the preceding section this is due to the higher evapotranspiration from Mgera both during the wet season and particularly during the dry season where the permanent vegetation with deep roots as compared to the cultivated catchment is able to extract soil moisture from the deeper soil layers.

Regarding the low flow this effect is enhanced by the fact that the recession constant for the baseflow (i.e. how quickly the groundwater storage is emptied) is higher for Mgera. Thus, first the groundwater storage at Mgera at the end of the rainy season is lower than at Muhu and Gendavaki. Secondly, the ground water storage is emptied faster than the ground water storage at Muhu and Gendavaki, which is likely to be the reason that the low flow for Mgera is so much lower as that of the two cultivated catchments. The higher recession constant at Mgera may be due to a slightly different geology compared to the other two catchments. However, it may also be due to the existence of the swampy area at the lower part of the catchment, where a certain part of the ground water may evaporate before it reaches the stream. However, both Gendavaki and Muhu also have a certain part of land which is more or less wet the year round. Therefore, when more detailed land use surveys are carried out in each of the catchments, the portion of the catchment that are swampy/wet should be given special attention. This also includes vinyungu cultivation, which is important in relation to water quality as well. In Mgera the trees in the lower part of the catchment may have the same effect as the swampy area, as the possible ability by the trees in this part of the catchment to utilize capillary water/groundwater may result in some exfiltration.

From Table 4.15 it can be seen that there is relatively little variation in the low flow values from year to year for Gendavaki and Muhu. The bigger difference for Mgera may because of the higher recession constant combined with the fact that the rain came very late at the end of 1993.

The values are generally higher for 1992/93 than for 1993/94. This is because the rain came late. Furthermore, it seems that there was less rainfall in 1992/93 than in 1993/94 (see Table 4.9).

### 4.6.3 Surface runoff and peak flow during heavy rainfall events

As a last analysis in this section we will look at one of the most important hydrological aspects in relation to agriculture and soil erosion in particular, namely the generation of surface runoff during heavy rainfall events.

As discussed previously the catchments are very similar physiographically, and, as the analysis in section 4.1 also showed, that they have very similar rainfall patterns in terms of total rainfall, temporal distribution, and frequency distribution of daily rainfall amounts. These similarities highly facilitate a comparison between the catchments in terms of the impact of the land use on the hydrological response.

When the hydrographs for each of the catchments are compared to the daily rainfall (figures 4.14 to 4.19), it is evident for all three catchments that a relatively small portion of the rainfall during the rainy season leaves the catchment as surface runoff during or immediately after the rainfall event. In spite of a number of days with more than 40-50 mm of rainfall (and for Gendavaki even one day with 85 mm) and a few 30-min rainfall intensities of 40-60 mm/hr there are no days in any of the catchments where the daily runoff exceeds 5 mm.

It can also be seen from figures 4.15, 4.17 and 4.19 that the peak flows during heavy rains are very similar for the three catchments, which is somehow surprising as it may be expected that the two cultivated catchments, Muhu and Gendavaki, where cultivation is taking place on hillslopes with slope gradients of 20-30% (and up to 100% on the steepest parts) would have higher peak flows than the forested catchment. Actually, the highest total daily runoff, 4.75 mm, is recorded at Mgera. However, it is likely that a main portion of this runoff originates from rain falling in the lower swampy part of the catchment and other areas close to the streams rather than being surface runoff from the forested hillslopes. It should also be kept in mind that a minor portion of Mgera is cultivated (approximately 15%).

Experience from a number of places in Africa has shown that most of the yearly soil loss often takes place during a few dramatic rainstorm. Quoting from research in Zimbabwe, Hudson (1981) states that 50% of the annual soil loss occurs in only two storms and that, in one year, 75% of the erosion took place in ten minutes !!! Near Ibadan, Nigeria, measurements of soil erosion showed that half of the annual soil loss can occur with between two and seven storms (Lal, 1976). Thus, a few of the heaviest rainfall events have been analyzed on an hourly basis. In Figure 4.20 are shown corresponding hourly values for rainfall and runoff in Muhu for 7th and 8th of March during which period the highest 30-min rainfall intensity during the whole water year was recorded. 28.6 mm of the 46.6 mm was recorded within an hour.

The rainfall event results in a dramatic increase in the stream flow as expected with such a heavy rainfall event. However, it is worth noticing that despite the fact that a total amount of 46.6 mm was recorded within 3 hours (and 28.6 mm within ½ hour) the hourly total streamflow never exceeds 0.4 mm and less than 2 mm out of the 46.6 mm of rainfall leave the catchment during the succeeding 24 hours after the start of the rainfall event.

It is also worth noticing that the rainfall event took place in March, where the soil moisture content normally is high and surface runoff is more likely to occur due to saturation during the rainfall events. In this case 120 mm of rain had fallen the preceding 7 days before the actual event. Hence, it may be expected that the soils have reached saturation. Thus, the surprisingly small amount of surface runoff may be due to good physical features of the soils in particular a high saturated hydraulic conductivity. This is supported by earlier measurements of the saturated hydraulic conductivity in Muhu, as measured with a double ring infiltrometer, revealed values of $7.7 \cdot 10^{-5}$ m/s (= 277 mm/h) for the topsoil and $4.2 \cdot 10^{-6}$ m/s (= 15 mm/h) for the subsoil. As the soils do not show any sign of sealing/crusting, the raindrop impact is not expected to result in a major decrease of the infiltration.

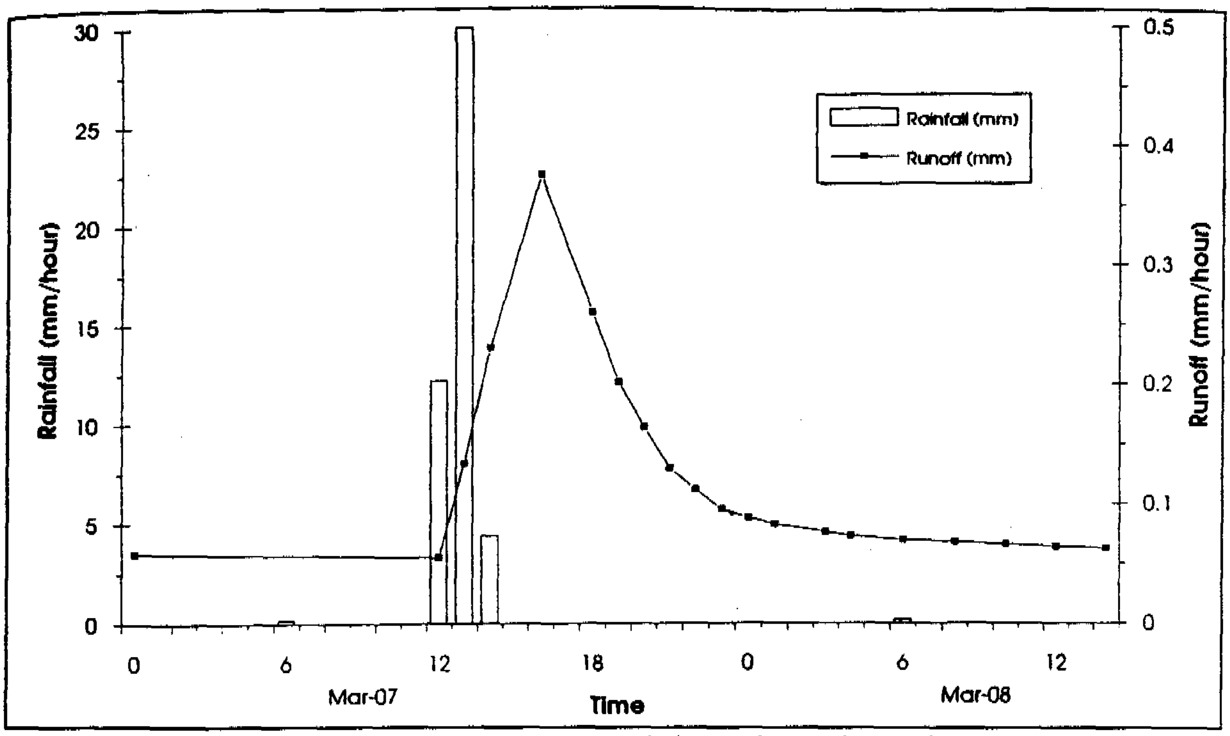


**Figure 4.20** - *Corresponding hourly values for rainfall (mm/hr) and runoff (mm/hr) 7th and 8th of March, 1994. 28.6 mm of the 30.0 mm rain from 12 to 13 o'clock was recorded within ½-hour, and was the highest recorded rainfall intensity within the 1993-94 water year.*

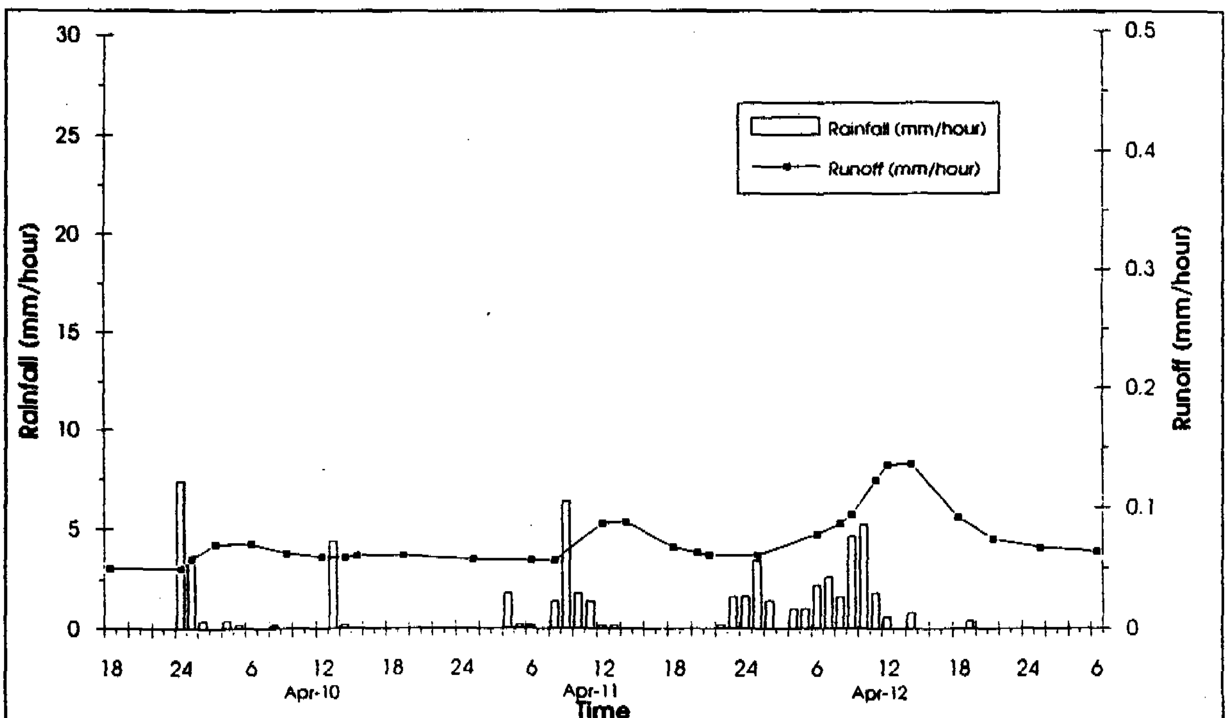


**Figure 4.21** - *Corresponding hourly values for rainfall (mm/hr) and runoff (mm/hr) 9th to 12th of April, 1994 at Muhu. The total amount of rainfall during the period is 60.4 mm.*

...nd water conservation measures which have been implemented on farmers field in the ... are still so few that they are not yet expected to have a significant effect on the relatively ...ce runoff.

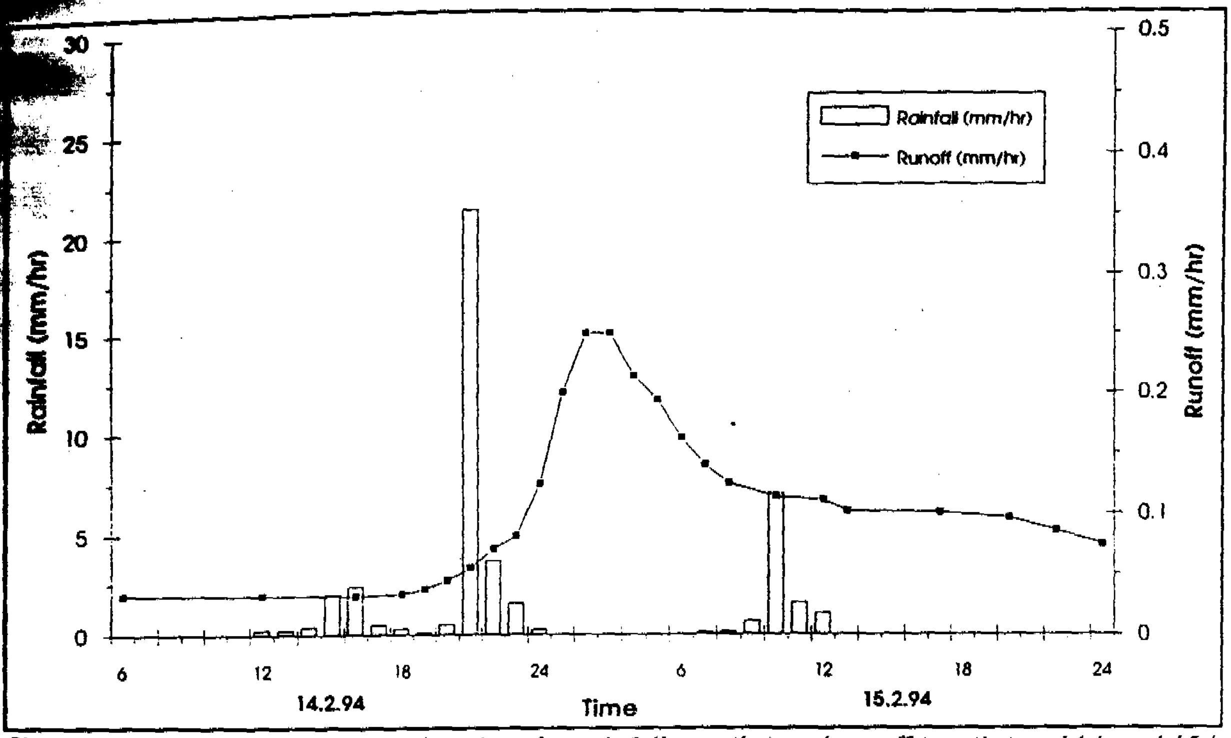


**Figure 4.22** - *Corresponding hourly values for rainfall (mm/hr) and runoff (mm/hr) at 14th and 15th of February, 1994 at Mgera. The highest 30-min. rainfall was 21.2 mm.*

For comparison between a cultivated and a forested catchment the corresponding hourly values for rainfall and runoff for Mgera on 14th and 15th of February 1994 are shown in Figure 4.22. Compared with heavy rainfall event for Muhu shown in Figure 4.20 it can be seen that the responses are similar. The slightly less abrupt increase in Mgera as compared to Muhu may partly be due to the less intensive rainfall. However, as discussed previously, a major part of the water recorded at Mgera may originate from the riparian areas.

Although the runoff caused by this heavy rainfall event is small, it should be emphasized that it is an average value. Thus in special sensitive parts of the catchments, i.e. the steepest slopes and areas where the infiltration conditions are poor and/or the rain is easily directed to the streams, a much larger percentage of surface runoff may occur. In this case special attention should be given to roads and footpaths. Based on observations in Muhu during the rainy season it is believed that a considerable part of the erosion in the catchment takes place in connection with foot paths and roads, which both act as a generator of surface runoff (due to low infiltration) and transport for surface runoff.

In order to illustrate the hydrological response from Muhu during rainfall events without very heavy rainfall intensities, corresponding values of hourly values of rainfall and runoff during a three day period from 9th to 12th of April, 1994 are shown in Figure 4.21. The total amount of rainfall during the period is 60.4 mm, compared to 46.6 mm in Figure 4.20. However, due to more moderate rainfall intensities it has a less dramatic impact on the hydrograph, but the total amount of rainfall leaving the is only slightly lower than for the rainfall event in figure 4.20. This could indicate that a high portion of the rainfall-generated runoff may originate from low lying areas close to the

## ...R QUALITY: DATA PRESENTATION AND ANALYSIS

### ...ollection and analyses of water samples

...tion

...ollection of water samples has so far been planned to take place monthly during the rainy ...n and every second month during the dry season as little variation in the water quality is ...ected to take place during this period as the water almost solely originates from groundwater.

...water samples have been collected at the outlet of each of the 4 catchments, including Ihaka. ...rmore, in Muhu catchment, samples are collected close to the residential area where villagers ...ch water for domestic use and, in Mgera catchment, where the stream leaves the forest reserve ...order to be able to assess the impact of the lower, cultivated part of the catchment on the water ...ality. The collection points are indicated on the maps in figures 3.1 to 3.4.

Unfortunately some logistical problems implied that no samples were collected during the months of November and December 1993 and January, February and April 1994. Thus the results so far only contain few samples collected during the rainy season. Thus, water samples collected in December 1994 are included although this is outside the period which is generally covered. The months where water samples have been collected are indicated in table 5.1.

**Table 5.1** - *List of months for which water samples have been collected and analyzed.*

| Month | Jun-93 | Jul-93 | Aug-93 | Sep-93 | Oct-93 | Mar-94 | May-94 | Jul-94 | Oct-94 | Dec-94 |
|---|---|---|---|---|---|---|---|---|---|---|
| Muhu gauging station | x | x | x | x | x | x | x | x | x | x |
| Muhu residential area | x | x | x | x | x |  |  |  | x |  |
| Gendavaki | x | x | x | x | x | x | x | x | x | x |
| Ihaka | x | x | x | x | x | x | x | x | x | x |
| Mgera gauging station | x | x | x | x |  | x | x | x | x | x |
| Mgera forest boundary | x | x | x | x | x | x | x | x | x | x |

Analysis

All the water samples have been analyzed by the Regional Water Engineer's water quality laboratory in Iringa. The analyses include physical, chemical, and microbiological analyses, as seen i table 5.2. The most important parameters in relation to evaluation of the impact of different types of land use

**Table 5.2** - *Water quality results for water samples collected from June 1993 to December 1994. The values for all measured parameters are average values for all the samples collected during this period.*

| | Unit | Maximum permissible amount[a] | Mgera | | Gendavaki | Ihaka | Muhu | |
|---|---|---|---|---|---|---|---|---|
| | | | Gauging station | Forest | Gauging station | Gauging station | Gauging station | Residental area |
| Number of samples | | | 9 | 10 | 10 | 10 | 10 | 6 |
| **PHYSICAL TESTS** | | | | | | | | |
| Colour | mg Pt/l | 50 | 15.8 | 23.0 | 34.0 | 16.8 | 44.3 | 14.0 |
| Turbidity | NTU | 30 | 8.1 | 14.0 | 14.7 | 14.6 | 26.0 | 13.4 |
| Conductivity | uS/cm | | 36 | 32.0 | 24.7 | 38.0 | 25.3 | 26.4 |
| pH at 25 °C | °C | 6.5-8.5 | 6.9 | 7.0 | 7.0 | 6.9 | 6.9 | 7.2 |
| **CHEMICAL TESTS** | | | | | | | | |
| Alkalinity | mg $CaCO_3$/l | | 16.1 | 12.4 | 12.0 | 16.0 | 13.8 | 13.6 |
| Hardness | mg $CaCO_3$/l | 600 | 48.3 | 35.0 | 35.8 | 20.0 | 38.5 | 41.8 |
| Calcium | mg $CaCO_3$/l | 300 | 2.8 | 3.5 | 3.5 | 3.2 | 2.6 | 2.1 |
| Magnesium | mg/l | | 9.9 | 6.3 | 6.6 | 6.8 | 7.8 | 8.7 |
| Chloride | mg/l | 200 | 1.7 | 0.6 | 1.7 | 1.1 | 1.2 | 0.94 |
| Sulfate | mg/l | 600 | 0.6 | 0.3 | 1.1 | 0 | 0.65 | 0.52 |
| Fluoride | mg/l | 8.5 | 0.05 | 0.16 | 0.14 | 0.19 | 0.08 | 0.25 |
| Ammonia | mg N/l | 0.4 | 0.04 | 0.06 | 0.05 | 0.07 | 0.065 | 0.04 |
| Nitrate | mg N/l | 11 | 0.13 | 0.03 | 0.22 | 0.11 | 0.14 | 0.09 |
| Nitrite | mg N/l | | TR[b] | TR | TR | TR | 0.003 | 0.001 |
| Iron | mg/l | 1.0 | ND[b] | ND | ND | ND | ND | ND |
| Manganese | mg/l | 0.5 | 0 | TR | 0.001 | TR | 0.003 | 0.02 |
| Permanganate Value | $KMnO_4$/l | 20 | 5.0 | 4.3 | 3.4 | 3.7 | 3.4 | 3.9 |
| **MICROBIOLOGICAL TESTS** | | | | | | | | |
| Total coliform | nos/100 ml | | | | | | | |
| Faecal coliform | nos/100 ml | 4 | 88 | 95 | 98 | 120 | 108 | 159 |

a) For water supply according to Tanzanian standard
b) ND: Not determined, TR: Trace

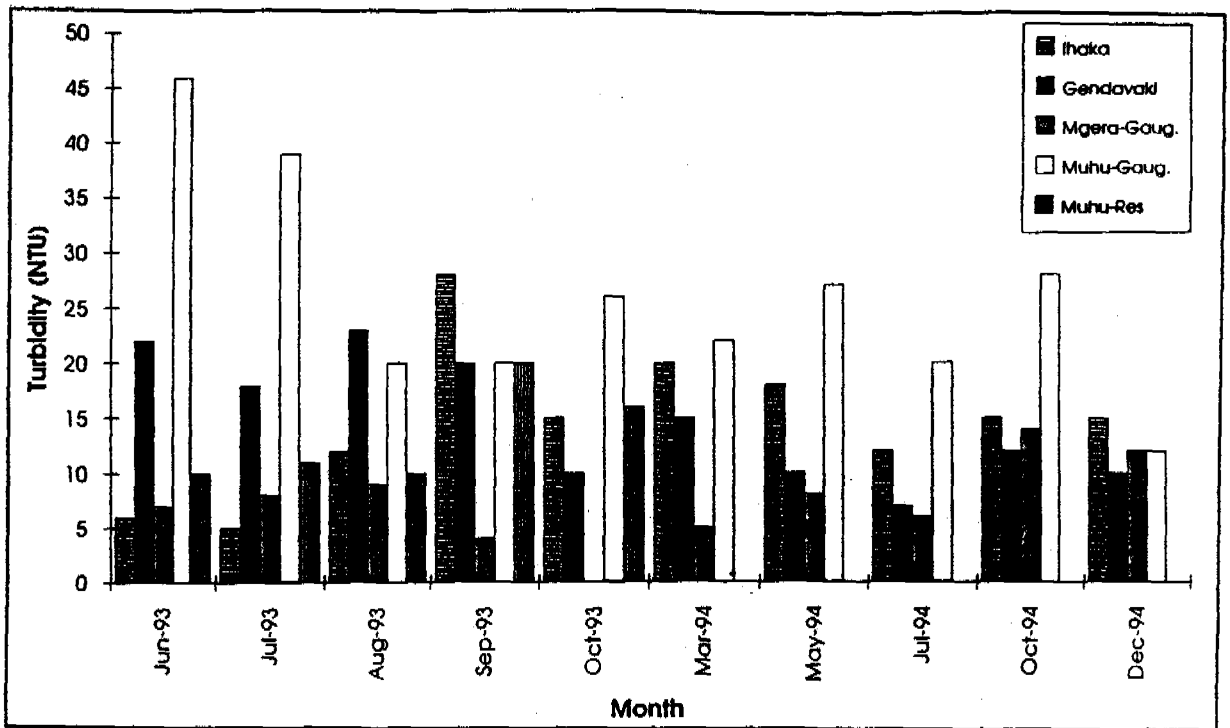


**Figure 5.1** - *The variation in turbidity (NTU). Where there is no column, there is no measurement.*

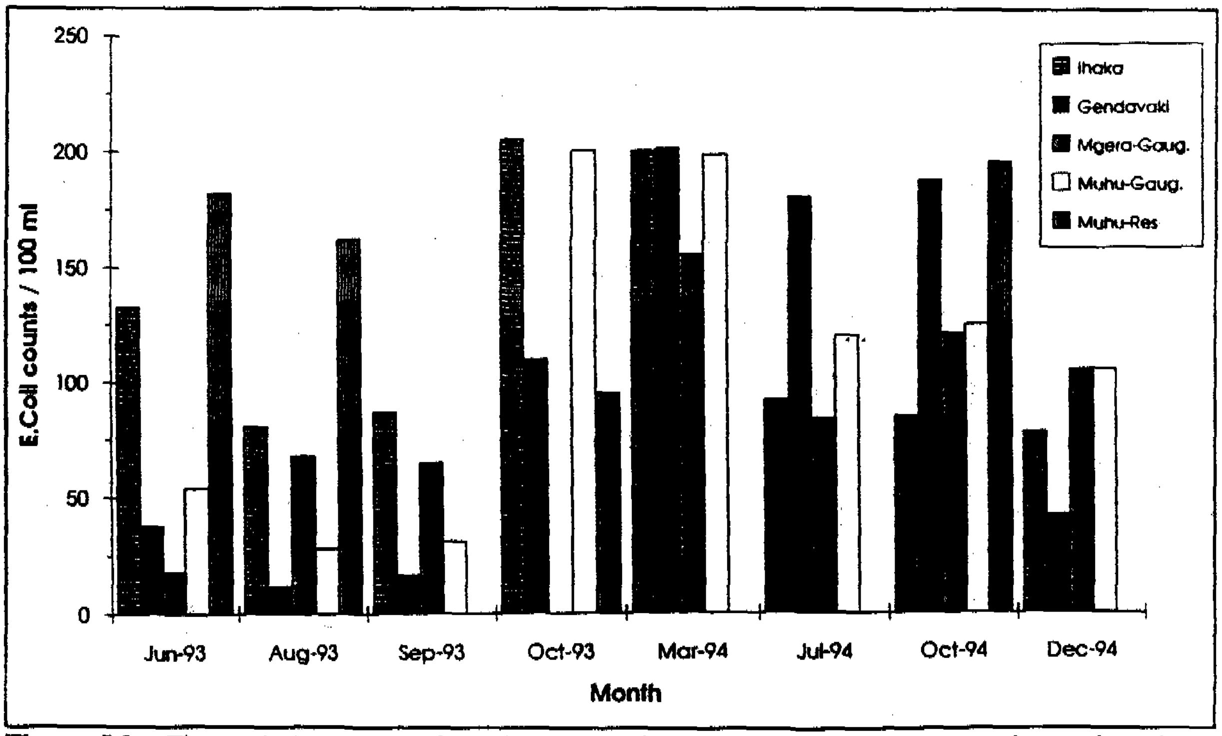


**Figure 5.2** - *The variation in faecal coliform (no / 100 ml). Where there is no column, there is no measurement.*

and management practice (including use of soil and water conservation measures) on the water quality are:

1) Turbidity:
This parameter will give an indication of the transport of suspended material in the water. Turbidity may be caused by a wide variety of materials brought to the streams from the adjacent areas where farming and other activities disturb the soil. Under heavy rainstorms, considerable amounts of topsoil may be washed to the streams. Much of the material is inorganic in nature and includes clay and silt, but a considerable amount of organic matter may be included too. As there is often a rather good correlation between the turbidity and the sediment transport, the turbidity can give at least some relative indications of the rate of soil erosion. Furthermore, high turbidity is one of the main reasons that villagers do not accept water from a certain source.

2) Colour:
The colour in the water originates from contact with organic debris in various stages of decomposition and inorganic elements as e.g. iron which is often one of the major colouring agents.

3) Ammonia, nitrate, and phosphorus:
This will give an indication of the amount of nitrogen removed from the fields by surface runoff (rainy season) or through leaching (most easily evaluated during the dry season when there is no surface runoff). Phosphorus has not been measured so far due to lack of chemicals.

4) Faecal coliform:
The presence of faecal coliform indicates faecal waste contamination by warm-blooded animals, mainly humans and livestock. It is a warning of more recent and more hazardous pollution than the presence of total coliform. Faecal contamination, which is the main cause of e.g. diarrhoea, dysentery, and typhoid fever, is the most common problem in relation to health risk caused by poor water quality.

The quality of the data is in general assessed to be good. However, there are a few surprising fluctuations in the e.g. the nitrate and ammonium content during the dry season, which may reflect a measuring error. The laboratory has been given some blank specimen for analyses, but the results were not ready at the time of writing. Corresponding analyses of some samples at another laboratory would also be advisable. Otherwise possible errors may be difficult to detect.

### 5.2 Analysis of results

In table 5.2 are given the average values of the parameters for which the water samples have been analyzed. The table includes all analyses carried out since the collection of water samples were initiated in June 1993. During the following discussion of the results the parameters most relevant in relation to evaluation of water quality from different types of land use (as mentioned in section 5.1) will be emphasized.

From table 5.2 it appears that ***faecal coliform*** counts are the only parameters that are above the permissible limit - far above as the lowest average value is 78 nos/100 ml (Mgera gauging station) as compared to the highest permissible value of 4 nos/100 ml. However, it should be mentioned that even the water from many water supply schemes often contains more than 4 nos/100 ml and during the preparation of the Water Master Plan in the early 1980's analysis of a large number of natural sources in Mbeya Region revealed that 45% had 0 E.Coli per 100 ml, 36% had 1-100 E.Coli per 100 ml and 19% had more than 100 E.Coli per 100 ml (URT/DANIDA, 1982b).

The highest value for faecal coliform is found at the most critical location, namely the residential area at MUHU, where a large number of villagers from Bomalang'ombe fetch their water. On the other hand it is not surprising that this is the location with the highest microbiological contamination, as this is the sample point with the expected highest human and livestock activity (mainly guinea pigs, chicken and goats). There are three farmers that graze their cattle in the sub-catchment upstream the point of sampling, and there is a cattle-watering point next to the stream, which certainly is an obvious source for severe bacteriological contamination of the stream. Furthermore, it is quite likely that the cattle from time to time drink water direct from the stream. Water is fetched from small water holes, and, as experienced from many similar places, the fetching of water itself is often a source of pollution.

The high rate of microbiological contamination corresponds very well with the fact that diarrhoea is a very severe problem in Bomalang'ombe, and that very few people boil their water. Thus to improve the water quality in the area, the possible sources of microbiological contamination should be identified, and as a starting point is it proposed that no cattle should graze in the sub-catchment upstream the point of collection of water for domestic purposes. Presently cattle of a few people are a health risk to a larger number of villagers.

Although the highest faecal coliform counts are found at the residential area, they are very high for all 6 locations, and although there is a considerable variation in the values from one sampling to another for each of the six locations all values are far above the maximum permissible value of 4 counts per 100/ml, meaning that the water at all 6 locations is continuously microbiological contaminated. It should be mentioned that cattle drinking water close to the gauging sites have been observed at both Gendavaki and Mgera.

Regarding the microbiological contamination at the forest boundary in Mgera catchment, it is surprising that the level is so high, actually it is higher than the contamination at the gauging site at Mgera, where part of the water originates from the cultivated area at the lower part of the catchment. However, during the last visit to the project, it was found out that the technician no longer collects the samples at the boundary itself but quite a distance from the boundary where there is vinyungu cultivation, claiming that there is no longer a permanent stream at the boundary where water can be collected. This is of course unfortunate, when the aim is to compare water originating purely from the forest with water which has been influenced by agricultural activity. A new collection point has now been selected a few hundred metres inside the forest which will ensure that the analyses will represent the conditions in the forest. Regarding the high content of faecal coliform at/near the boundary, the flow of water here is much less than at the gauging station. This implies that the same amount of pollutant added at this point will result in a much higher concentration. This may partly explain the higher amount as compared to the gauging station. Analyses of blank specimens have been made recently to check the reliability of the microbiological analyses but the results were not ready at the time of writing.

The amount of faecal coliform varies considerably during the monitoring period as shown in Figure 5.2. This is to be expected, as a single/few sources can cause a considerable rise in the faecal coliform content, and therefore considerable fluctuations even within the same day will be common. Generally the lowest content is found in the samples collected during the dry season 1993.

Regarding the ***turbidity and colour*** the highest values are found at the gauging station at Muhu. The high turbidity at this location corresponds very well with the fact that a considerable sediment transport can be observed here the year round, so that desilting is necessary every time during the weekly visit to the site in order to maintain a proper control for the measurement of discharge. The sedimentation is considerable even during the dry season despite the fact that there is very little surface runoff from the cultivated fields during this period. Increased bank erosion, among other things as a result of vinyungu cultivation could be a likely explanation. However, the average values given in table 5.2 are still below the permissible values, but from Figure 5.1 it can be seen that for the two first water samples from this location the turbidity was above the permissible value, and that the value for colour was close to the permissible value. From Figure 5.1 it can also be seen that for the other locations none of the samples have values for turbidity and colour above the permissible limits.

From Figure 5.1 it appears that the turbidity measured at the gauging station at Mgera is considerably lower than from the cultivated catchments and from the Muhu gauging station in particular. The existence of a swampy area in the lower part of this catchment is believed to be one of the major reasons for the low turbidity at this point. The surprisingly high turbidity at the forest boundary is probably due to the fact that the samples have actually been taken outside the forest boundary as discussed previously. However, it has also been observed that a considerable amount of fine organic material, with low specific gravity, is transported in the stream inside the forest even during the dry season where the flow velocity is low.

In contrast to the microbiological contamination, the values for colour and turbidity are rather low at the residential area at Muhu, which may reflect the protection of the stream that has been initiated at this upper part of the Muhu catchment. Unfortunately the technician from the water quality laboratory has not collected samples at this location for most of 1994. However, collection of samples at this point will be re-initiated, and this location will be given special attention due to the high priority this part of Muhu catchment has been given by the village government and HIMA. Since the last water sample was collected here in October, most of the vinyungu cultivation here has been abandoned, and regeneration of natural vegetation, mainly grasses, has taken place, acting as an important buffer zone for material transported from above. At the same time the area itself does not act as a source of pollution. Thus it will be interesting to follow which effect this may have on the turbidity and the water quality in general.

It should be emphasized that most of the samples have been collected during the dry season. In the coming water year, a higher collection intensity is planned to take place during the rainy season in order to get a better picture of the water quality, especially the turbidity, during heavy rains, as that will give a better idea of the extent of soil erosion in the different catchments. It is also proposed that the weekly siltation at Muhu should be measured (in terms of buckets filled with sediment) as this at least will give a picture of the relative variation in the amount of sediment transport.

It was planned that a regular ***sediment sampling*** programme should be included in the monitoring, in order to get a more precise estimate of the extent of erosion/sediment transport. Such monitoring includes a lot of visits to the site, and it was felt that it would be too much to include it from the start of the monitoring. However, as all the other activities now have become routine for the technicians, and as the use of local observers has worked well, it is felt that it is the time to include sediment sampling in the monitoring programme.

Regarding the ***chemical composition*** of the water samples the chemical pollution of the water is not a problem. However, it should be noted that no analyses of ***pesticides*** have been carried out so far. As the use of pesticides, in the vinyungu cultivation in particular, may constitute a health risk, it is proposed that analyses of pesticides should be included in the monitoring. It is proposed that the agricultural unit makes a small survey of what type of pesticides (fungicides, insecticides and herbicides) are used by the farmers and at what time of the year and then include analyses of these types of pesticides in the water quality analyses during this water year (1994-95). The Government Chemist in Dar es Salaam has got a new laboratory in September 1994 and is now able to analyze the water for a number of pesticides.

Furthermore, it should once again also be emphasized that most of the samples originates from the dry season and therefore do not give a sufficient information on the chemical composition during periods with heavy rain. However, the few samples collected during periods with rain (18-19/3 and 5-6/5 1994), also contained very small amounts of ***ammonium and nitrate*** - far below the permissible level. The low level of ammonia (0.04 to 0.07 mg/l) and nitrate (0.03 to 0.22) during the dry season also indicates that very small amounts of nitrogen are leached out of the root zone. For instance, with a yearly runoff of 393 mm the average contents of ammonium and nitrate of 0.065 g N/l and 0.14 mg N/l at Muhu gauging station corresponds to a yearly leaching of 0.8 kg N/ha, which is surprisingly low. This indicates a soil with a low availability of nitrogen.

For comparison it can be mentioned that it is not unusual to find nitrate concentrations of 10 mg N/l in the streams in Denmark and that 20-50 kg N/ha is leached yearly - especially on sandy soils. This is mainly ascribed to the very high rates of application of manure and artificial fertilizers in Denmark and due to the fact that leaching is taking place outside the growing season, which is normally not the case in the monitored catchment due to the lack of surplus rainfall outside the growing season. Due to lack of chemicals no analyses of phosphorous have been carried out, but based on the low content of nitrogen the phosphorous content is also expected to be very low.

The ***alkalinity*** and the content of ***calcium and magnesium*** vary only little between the different catchment. As these parameters mainly are determined by the type of soil profiles and the geological formations (and liming where it is practised), this could indicate that the parent materials are similar in the catchments.

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