EFFECTS OF MSWISWI WATERSHED DEGRADATION ON STREAM FLOW IN USANGU VILLAGE IRRIGATION PROJECT

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BY

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ABSTRACT

The effect of Mswiswi watershed degradation on stream flow was investigated as one of 5 watersheds used by Usangu Irrigation Project as source of water. The watershed was calibrated upon itself by establishing four watershed degradation scenarios as the basis for comparison of watershed degradation parameters and stream flow characteristics. The established degradation scenario were 1960-65, 1965-75, 1975-86 and 1986-92. The 1960-65 degradation scenario was taken as the control period i.e the period for which watershed degradation was at the minimum level. Therefore all parameters of watershed degradation and stream flow of certain probabilities in 1960-65 were compared with the same parameters in other three scenarios.

Watershed degradation evidence analyzed from aerial photographs of 1977 and 1992 shows that: watershed forest loss was 0.105, 0.032 and 0.497 km^2/year for mixed forest,forest reserve and low dense miombo woodland, respectively. Soil degradation through gully expansion was 0.049 km^2/year.

The study shows that precipitation in Mswiswi watershed is decreasing from 1963-1986. This has been evidenced by decreasing trend of 5-year moving averages of precipitation and precipitation of certain probabilities. Comparison of watershed degradation parameters in four degradation scenarios shows that there were a differences among scenarios as a result of degradation. There was a general

decreasing trend of parameters such as watershed storage and watershed loss factor from degradation scenario of lower order (1960-65) to scenario of higher order (1986-92). This means that the trend of decrease in watershed degradation parameters was from 1963-1989. Watershed degradation parameters such as curve number and watershed degradation factor were, on the contrary, increasing from 1963-1989. The decrease of watershed loss and watershed storage indicate that watershed was degrading as has been evidenced by watershed forest loss. Similar indication of watershed degradation was shown by increase of curve number and watershed degradation factor.

This study shows that there was a relationship between increasing trend of runoff and increasing or decreasing trend of watershed degradation parameter from one degradation scenario to another for a particular probability of exceedance. Runoff of 10 % probability was increasing from watershed degradation scenario of lower order to scenario of higher order as watershed storage and loss factor of the same probability was decreasing. The trend of changes in base flow of particular probability of exceedance was more related to the trend in which watershed degradation factor of the same probability was varying.

Stream flow from Mswiswi watershed is affected by both climatic changes and watershed degradation. To evaluate the effect of watershed degradation alone, the developed runoff and base flow models were run for equal rainfall events, so as to see how the watershed in the process of degradation in different periods was

responding or would respond to the same rainfall events. The results of model utilization show that runoff was increasing as the watershed was degrading for equal rainfall events. In the case of base flow, the results of model utilization show that watershed degradation was causing cyclic trends of base flow variability. The maximum and minimum base flow for equal rainfall were having recurrence intervals of ten years. The magnitude of maximum and minimum base flow was decreasing with time as watershed was degrading for equal rainfall events.

DECLARATION

I, Gerald Wanda Sere Malongo, do hereby declare to the Senate of Sokoine of University of Agriculture that this dissertation is my original work and has never been submitted for higher degree in any other University.

Signature

6th May, 2017

Date

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DEDICATION

Dedicated to my son Joash Geraldovich and my daughter Susan Geraldina.

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LIST OF ABBREVIATIONS AND SYMBOLS

(a,b)	Watershed coefficients accounting for changes in watershed characteristics affecting runoff
(n,m)	Watershed coefficients accounting for changes in watershed characteristics affecting baseflow
BF	Baseflow
B_j	The regression coefficient for Y on X station during the j^{th} month.
C	Cropping factor.
C_{dc}	Cumulative water deficit or excess.
CN	Watershed curve number.
e	Exponent
E	Evapotranspiration
e_i	The random variate assumed normally distributed with mean = 0 and standard deviation = 1
F_0	Forest or gully area at the beginning of reference period
F_N	Forest or gully area at end of reference period
F_t	Forest or gully area at time t
ha	Hectare
K	Soil erodibility
LS	Length slope factor
Mm^3	Million cubic meter
p	Rainfall

Ppt	Precipitation
Q -	Runoff
Q_{ix}	Discharge at station X during the i^{th} month
Q_{iy}	Discharge at station Y during the i^{th} month
Q_{mjx}	Mean discharge at Station X during the j^{th} month within an annual cycle of 12 months
Q_{mjy}	Mean discharge at Station Y during the j^{th} month within an annual cycle of 12 months
q_p	Peak runoff rate
r	Correlation coefficient
r_j	Correlation coefficient between flows at station X and Y during j^{th} month
S_{jy}	Standard deviation of discharge at y station during j^{th}
t	time in years
W	Water yield
WD	Watershed degradation scenario
WDF	Watershed degradation factor
WLF	Watershed loss factor
X_{aNp}	Watershed degradation indicator of p % probability of exceedance in N^{th} degradation scenario
X_{b0p}	Watershed degradation indicator of p % probability of exceedance in 0^{th} degradation scenario
X_c	Truncation level

X_i	Annual water yield of the year (i)
y	year
Y_{aNp}	Stream flow of p% of exceedance in the N^{th} degradation scenario
Y_{bop}	Stream flow of p% of exceedance in the 0^{th} degradation scenario
Y_s	Storm sediment yield
ΔS	Change in watershed storage
Δt	Time increment between periods under consideration

1. INTRODUCTION

1.1 Background

Stream flow in a given watershed is a consequence of rainfall, but also depends on other factors such as terrain configuration, size of watershed, parent rock, vegetation cover and erosion processes (Kostadinov and Mitrovic, 1994). Therefore any human activity which affects the above factors will affect the watershed storage and stream flow.

The most important watershed characteristic, which is significantly affected by human activities, is vegetation cover. Land use has a very strong impact on vegetal cover and hence on erosion and watershed degradation (Houerou, 1993). Deforestation in watersheds is affecting large areas outside the watersheds, and negative effects can be recognized along the entire water system. Siltation in dams, soil erosion, landslides and severe flooding in the lowlands are some of the results of watershed degradation. Indeed many places in Tanzania during the last few years have been hit by floods causing severe damage and loss of human life. Landslides and severe soil erosion caused by deforestation in the watersheds have been shown to have negative effects on the water supply as experienced in the Uluguru mountains (Mvena, 1993).

The Usangu Plains have been earmarked by the Government of Tanzania for intensified irrigation development (BACAS, 1993). But in other areas of Tanzania watershed degradation is one of the major threats to sustainable irrigation development. The government and agricultural organizations have stepped forward in implementing irrigation projects in Usangu Plains. The Usangu Village Irrigation Project (UVIP) is one of these projects. The UVIP is a project of five traditional irrigation schemes covering approximately 3200 ha viz. Motombaya (400ha), Ipatagwa (500ha), Mswiswi (800ha), Majengo (530), Meta and Lunwa (1000ha). Their sources of water for irrigation being Mlowo, Ipatagwa, Mswiswi, Mambi, Meta and Lunwa rivers respectively. These rivers originate from Mporoto mountains.

Parallel with irrigation development in Usangu Plains, there is also both increase in human and livestock population. The study by BACAS (1993) shows that there is an increase of human population of 30% from 1978 to 1992 and an increase of livestock population of 90% from 1984 to 1992.

According to Mvena (1993), watersheds of rivers used for irrigation by UVIP may be experiencing degradation for the following reasons. First, as human population increases the demand for natural products from trees such as fuel wood, timber, fodder medicines, etc also increases. This results in land clearance and deforestation which removes the protective cover of the soil and sets in erosion.

Second, the growth of population is often accompanied by inappropriate farming methods which facilitate soil erosion. For example clearing of hillsides for

agricultural can result into extensive sheet and gully erosion (Mungongo,1991; Mvena, 1986).

The present and future goal of irrigation development in Usangu Plains is to satisfy the demand and supply of food through land extension. With increases of population migration to the Usangu Plains, the demand for water for irrigation is also increasing but the main question is whether the watersheds are able to supply the quantity required under the prevailing situation of watershed degradation.

Irrigation of the Usangu Plains has been the subject of several investigations. But the study by Commonwealth Secretariat (1978) forms the basis of all studies ever carried out. The study by the Commonwealth Secretariat estimated 68,000 ha as an area that could be irrigated in Usangu Plains under improved water use efficiency and total potential area for irrigation could be doubled to 137,000 ha with construction of storage dams.

But due to potential problems associated with watershed degradation in Poronto mountains and subsequent hydrological impacts experienced, there is doubt if the targeted 137,000 ha could be irrigated in the near future. Because of this doubt, it is difficult to predict the amount of water available for development based on available hydrological data. Since the available streamflow data collected in past year does not reflect the reality of the as future the flow is affected by the watershed degradation.

This fact of using the past data without accounting the effects of watershed degradation is reflected on what is happening with Mtera dam hydro-electric supply. Rivers from Usangu catchment drain to great Ruaha river which is the source of electricity generation. The shortage of electricity generation from Mtera dam may be regarded as the effect of Usangu watershed degradation and irrigation development.

The follow up of Commonwealth Secretariat study has been the implementation of irrigation projects in which Usangu Village Irrigation Project is one of them. The management of irrigation projects in Usangu Plains is not linked with what is happening in the water sources. It is a common practice in Tanzania, when new irrigation land is opened up, water engineers and meteorologists are rarely at hand to measure the effects of changes in land use in the watershed will have on water resources. Forests are felled or burned and natural grasslands are ploughed without reference to catchment conservation. The main data available for irrigation development are the records of stream flow measured by water engineers in their assessment of local and regional water resources. Many years of intensive design of irrigation schemes based on hydrological data by mathematical analysis have been devoted to studies of flood and drought, and have led to great advances in irrigation development. But it has rarely been possible, however, to relate these studies of river flow to specific changes in the land use and management of the watersheds, although deterioration in stream flow regimes have often been associated with land misuse.

1.2 Research problem

Although the study by the Commonwealth Secretariat revealed that surface water supplies are presently adequate to meet the needs of irrigation development in Usangu Plains, future availability of such supplies nevertheless remains uncertain. Moreover it is not clear what effect does the watershed degradation has on stream flow. Therefore for future development of Irrigation in Usangu Plains, there is a need to investigate the extent stream flow has been affected by watershed degradation and the potential area that could be irrigated now. More specifically, the following questions can be raised in the context of the proposed study:

- Does Mswiswi watershed degrades? And which are the evidences or indicators of the degradation?
- What is the criterion for watershed degradation?
- Which are the streamflow characteristics are affected by watershed degradation?
- What is the trend of streamflow of characteristics?
- Is there any relationship between the trend of streamflow characteristics and watershed degradations indicators?
- What is happening with runoff of 10% probability with respect to watershed degradation?
- How can effects of watershed degradation on streamflow be quantified and evaluated?

1.3 Objective

The main objective of this study was to investigate the effects of watershed degradation on streamflow characteristics in Usangu Plains. The research has focused on degradation of upstream watershed of Mswiswi river which is among five rivers used by Usangu Village Irrigation Project.

In order, therefore, to give direction and clear guidelines for the data analysis, the following specific objectives were developed:

1) To identify and quantify the evidences (indicators) of watershed degradation;
2) To determine stream flow characteristics of Mswiswi river;
3) To determine the relationship between watershed degradation and stream flow characteristics.

1.4 Hypothesis

This study and the methodology adopted were based on the following hypothesis: Mswiswi watershed is degrading and this degradation is affecting the trend of streamflow characteristics (runoff and baseflow).

1.5 Study area

The research was conducted on Mswiswi watershed located in Mbeya rural district. The study area is bounded by Mbeya-Iringa highway in the north and Poroto mountain divide in the south, and Mambi river in the east and Umbrobo river in the west (Fig 1.1). The streamflow gauging station is located 1 km upstream from Mbeya to Iringa road and raingauge is located at Irambo (Fig 1.1).

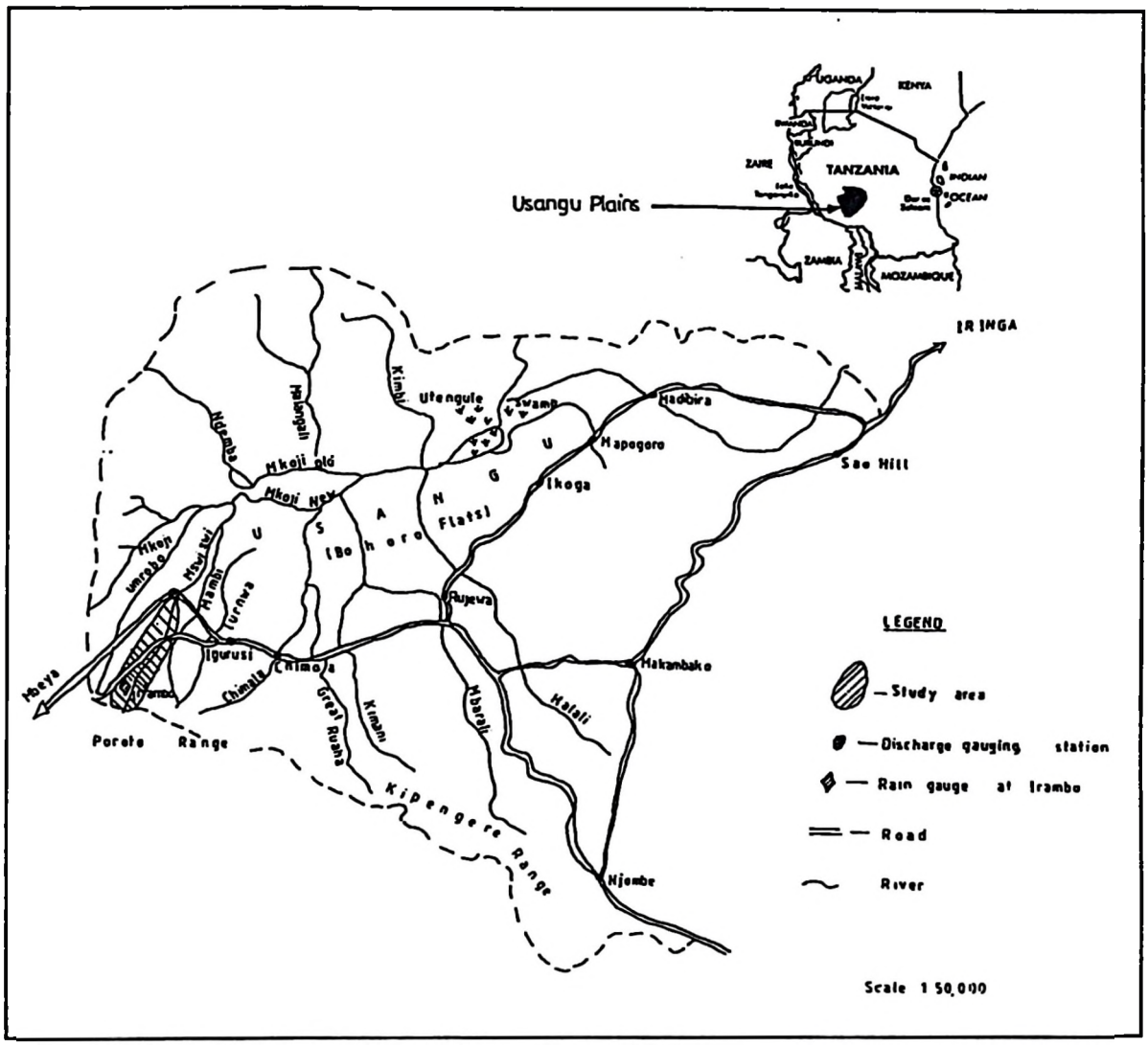

Fig 1.1 Usangu Plains drainage systems and location of study area - Mswiswi watershed

2.0 LITERATURE REVIEW

Watershed degradation in a general way can be defined as loss of watershed productivity, quantitatively or qualitatively through various processes such as erosion, wind blowing, salinization, waterlogging, depletion of nutrients, deterioration of soil structure, pollution and deforestation (Morgan, 1981). Deforestation, soil erosion and sediment load in streams are the main evidence of watershed degradation. The effects of the above indicators of watershed degradation are well known, but there are only very general estimates of the area affected, the rate at which they occur, the relationships between various forms of land use and degradation hazards and losses of productivity which occur (Stocking, 1987).

There has been an upsurge of interest in relation to the effects of watershed degradation on streamflow both in tropical and temperate regions. The present state of knowledge in the two regions is reviewed in order to understand the methods used in identification, quantification of watershed degradation parameters and their relationship to stream flows.

2.1 State of Knowledge in Tropical Regions

Deforestation is the major cause of soil degradation, erosion and sedimentation in many countries. In Africa, due to population increase, forests are cleared for crop production, livestock grazing and for fuel wood. Up to now, there have been several

state of the knowledge reviews on the effects of forest cover removal in the humid tropics on water attributes (Nik 1992), although there is little quantification of the processes. Studies in tropical countries such as Australia, Tanzania, Kenya and Taiwan on conversion and removal of forest to other land use characteristically revealed increases in runoff after conversion of evergreen montane forest to agricultural land (Pereira, 1967, Shutze and George, 1987).

Some of the earlier reports on erosion in East Africa have been reported by Thompson (1939) (cited by Lal, 1977). A comprehensive review of erosion as an indicator of watershed degradation in Tanzania has been published by Rapp et al (1972). Erosion research data in Tanzania are available from Mpwapwa, Tengeru and Shinyanga. Rapp et al (1972) reported a negligible soil loss from thicket and grass plots. Dagg and Blackie (1965) studied water balance of cultivated and forested catchments with areas of approximately 20 hectares during 6 water years (1957-1963) at Mbeya in Southern Highlands area of Tanzania. A calculation based on Dagg and Blackie (1965) published values gives an average ratio of runoff to rainfall of 0.25 for the forested catchment (mean annual rainfall 1598mm) and average ratio of 0.64 for the cultivated catchment (mean annual rainfall 1969mm). The study show cultivated catchment yield more runoff than forested.

The report by Rapp et al (1972) on Morogoro river catchment shows that the catchment was degrading. The sediment yield was 390 tons/km^2 on average or probably 10 times as much from the cultivated area and runoff coefficient is 0.40

taken over five years (1966-1970). Relating this study with study by Dagg and Blackie (1965), it can be concluded that more runoff comes from the catchment which is degraded.

Christiansson (1989) compared sediment yield and soil denudation rate in four catchments near Dodoma and one at Arusha by measuring the eroded material in each dam located in each catchment. The study demonstrated that the difference in sediment yields from the catchment was due to soil type, vegetation cover, rainfall intensity and amount.

Makungu (1992) used an agrohydrological model for predicting the effect of animal grazing on land degradation in semi- arid areas. Although the model can be used to predict runoff and soil erosion from grazing lands but it is limited at field level i.e cannot be used for the whole grazing watershed.

Results of soil erosion research from Kenya have been published by Thomas et al (1989). The publication show that most of the studies are limited to plot experiments and not to watershed scale. For example, Lininger (1989) assessed water balance in semi-arid highland of Laikipia- Kenya in relation to land use, soil erosion and productivity by comparing the runoff from two plots, one with overgrazing and other with controlled grazing. Blackie et al (1979) determined the effects of land use change from indigenous forest to tea estates by comparing two adjacent watersheds in Kenya, one under forest and another where 54% of the area was converted to tea

estates. The long term value of water use by the forest was found to be 92% of Penman E_o compared to 84% for partially covered watershed. Fissiha et al. (1989) investigated the effect of grass-strips in reducing soil loss and runoff on Labete-Kenya nitisol by using twelve runoff plots. The runoff plots were arranged in completely randomized block design with four treatments consisting of a control (with no grass strips and 0.5m, 1.0m and 1.5m wide grass strips).

In Uganda Hutchinson et al (1958) (cited by Lal, 1977) found from their investigation at Namulonge that 10 times more runoff occurred from the bare plots than from grass- covered plots and that grass mulch was twice as effective as stone mulch in terms of runoff control.

In Zimbabwe, Scoones (1992) used population density trends, cattle production parameters and cumulative stocking levels to detect rangelands degradation. In this study he finally concluded that the existing data on livestock density, production parameters and cumulative stocking rates rate from the study area cannot be used as evidence for degradation but simply as evidence of apparently reversible density dependent responses. From Tagwira's (1992) report on work of Hudson in Zimbabwe, runoff was reduced from 271 mm to 21 mm when soil cover gauze was introduced compared with bare field. It was clear from this study that, effects of soil cover gauze to reduce runoff can make significant contribution to infiltration into soil and consequently ground water levels. Whitlow's (1988) (cited by Scoones, 1992) study of soil erosion levels and hazard in Zimbabwe indicated that the study area was

severely eroded. This was assessed from the degree of exposed bare ground and the number of gullies observed during dry season of 1985. In another study conducted in a high rainfall region of Zambia, Mumeka (1986) (cited by Gaile et al., 1995) reported increases in runoff following clearance of Brachystegia woodland for agricultural use. The average annual increase in runoff ranged from 194 to 230 mm for the two treated catchments.

2.2 State of Knowledge in Temperate Regions

In the temperate regions under the influence of normal atmospheric conditions it has been demonstrated that watershed forest degradation generally leads to increase in streamflow, principally due to reduction in evapotranspiration losses (Robinson and Newson, 1986; Rodda, 1976; Newson 1979). Investigations carried by Kostadinov and Mitrovic (1994) in West Serbia have shown the significant impact of forest cover in the watershed on maximum annual discharge and specific discharge.

There are several methods used in different parts of the temperate regions in identification and quantification of watershed degradation indicators. Meuser(1990) used precipitation-runoff model in small watersheds ($< 1 km^2$) to simulate effects that vegetation cover has upon water balance and especially upon runoff. In that study the watershed was given three treatments; 90 %, 50% and 25% of vegetation cover. Prato et al.(1989) used geographic information system(GIS) to assemble and retrieve the physical parameters required to estimate sheet and rill erosion and water quality

in Idaho's Tom Beall watershed. Forero (1989) used aerial photography and a geographical information system to gather information about land use changes in San Francisco Bay. Roy (1966) used aerial photo techniques in mapping and analysis of gully erosion in the forest types of upper Damodar Valley. Thomas et al. (1984) showed that the amount of soil lost to concentrated flow erosion could be quantified using highly accurate photographs taken at critical intervals in cropping cycles. They used aerial photography to estimate annual soil loss in Athens and Georgia by measuring elevation and width of the gully.

Many studies have been conducted in assessing the effect of watershed degradation on streamflow in temperate regions. Ng and Marsalek (1989) conducted investigation on the effects of urbanization on streamflow in the Waterford river basin using Hydrological Simulation Program - Fortran (HSPF) model. HSPF is compressive continuous simulation model for predicting watershed hydrological response, water quality, agricultural chemicals and environmental risk assessment. The impact of future urbanization was simulated by means of the HSPF model, which was calibrated for the existing condition. The calibrated model was applied to three hypothetical future land use scenarios representing various increases in the basin imperviousness. Barringer et al, (1994) conducted a pilot study to determine whether significant trend exists in the baseflow and overland runoff characteristics in two sub-basins with different percentages of urban/built- up land. The study showed that flow and flow variability of the streams draining these subbasins have increased over time. However, the cause of these changes cannot be readily determined from the data, nor,

it is not clear whether the increased flow variability lies outside the natural range of flow variability of the streams draining the subbasins. Hicks et al,(1991) investigated the long term effect of logging on streamflow by three watersheds and three treatments: watershed 1(WS1)- clearcut and burned, WS2- unlogged control, and WS3- 25 % patch-cut logged and burned. This study shows that water yield in August increased by 59% after 25% of the area of WS 3 was patched-cut logged and burned in 1963. In contrast to WS1, however, water yields from WS3 in August were consistently greater than predicted for 16 years following the start of logging, through to 1978. The contrasting responses of WS1 and 3 to logging are thought to be the result of differences in riparian vegetation caused by different geomorphic conditions. Park et al, 1994 considered curve number and storage as watershed degradation parameters in evaluating the impact of best management practice on watershed runoff.

In temperate regions, many conceptual computer models have been developed for estimation of watershed response to rainfall events. Among these models, EPIC (Erosion / Productivity Impact Calculator) (Lopez at al, 1994), AGNPS (Agricultural Nonpoint Source) (Young at al,1989) and ANSWER (Areal Nonpoint Source Watershed Environment Response Simulation) (Montas,1992) are the most comprehensive and notable ones. However, such models generally contain a large number of parameters that need to be calibrated, requiring an extensive data from the watershed. EPIC and ANSWER models are limited in the size of watershed they can deal with, require very extensive input, or are too complex to run on anything other than a mainframe computer. AGNPS model was developed to analyze and provide

Despite the diversity of methodology used, the studies carried in both temperates and tropics have one thing in common, that is, the design of treatments in watershed experiments. There are two types of methods used in assigning treatments. First, the watershed to be treated is calibrated against an adjacent undisturbed control watershed so that the streamflow data from the two watersheds are compared. Second, same watershed is given different treatments in plots by either cutting totally or partially the trees and then comparing the flows from these treatment plots.

The problem with the first approach is that, it is rare to find undisturbed watershed in Usangu Plains where this study was carried out. All the adjacent watersheds to Mswiswi watershed are disturbed and their data are not continuous. Also the first approach assume that physiographic characteristics of the control watershed is the same as the treated watershed, the fact which is not always true for adjacent catchments. The larger the area the more likely it is that local effects of geology, soil type and depth and vegetation will tend be masked or average out, and the similar runoff will be from similar basins (Winter, 1989). On small scale, however, local differences in geology have a significant effect on runoff, as observed by Winter, (1989). He found that three Mirror watersheds were yielding different runoff although they were adjacent and similar had in soil and vegetation cover. The principal difference in the geologic characteristic that has a significant effect on streamflow in the three watersheds is in the volume, thickness and distribution of glacial drift.

The second approach (plot experiments) is environmentally not acceptable and runoff from small plots does not resemble to watershed runoff(Higgins 1989). Plot experiments which are particulary favoured for study of soil erosion in both temperates and tropics, suffer severely from sampling problems and edge effects when used for water balance studies, and extrapolating to a large scale is frequently impossible (Edward, 1977). Although plot experiments may give more insight into the nature of physical processes, any physical models so derived must ultimately be verified and assessed in relation to catchment data (Edward, 1977).

Due to the fact that there is no undisturbed watershed to be used as control and in order to avoid problems associated with plot experiments, an alternative approach is proposed in this study.

In this study the watershed is calibrated upon itself by dividing the period of streamflow records into watershed degradation scenarios according to periods for which there is watershed yield deficit or excess. Each watershed degradation scenario is regarded as a treatment because each of them represent a different condition of the watershed due to degradation. The first watershed degradation scenario is treated as control i.e before degradation while the other scenarios represent the degradation periods. Watershed degradation parameters and streamflow data of one scenario are compared with those of other degradation scenarios. Similar approach of calibrating watershed upon itself has been used by Dreher at al. (1989) (cited by Bradley and Keneth (1991). Dreher at al. used flood frequency analysis for evaluating watershed

conditions with rainfall-runoff models. They compared two hypothetical conditions for Salt Creek basin to determine the increase of flood frequency caused by urban development. The first was the predevelopment condition, where only 1 percent of the basin was impervious. The second was the final development condition, with 11 percent impervious surface.

In instead of hypothetical conditions, this study is utilizing natural different watershed conditions formed in each scenario due to continues process of degradation to make comparison of streamflow characteristics in different scenarios. Also, this study, the degradation scenario of lower order (before degradation period) and the other scenarios of higher order (after degradation) corresponds to predevelopment and final development condition of watershed in Dreher's method.

Bradley and Keneth (1991) reported that Dreher et al. (1989) didn't consider the relation between two hypothetical conditions, i.e whether the predevelopment condition was influencing the flood occurrence in final development condition. In this study degradation scenarios are related because of influence of antecedent moisture condition of degradation scenario of lower order to streamflow in other scenarios of higher order. Since antecedent moisture condition depend on rainfall (Chow, 1964), the influence of one degradation scenario to another, is eliminated by keeping the rainfall event in each degradation scenario constant when running the streamflow-rainfall models through the degradation scenarios. This relatively makes the degradation scenarios independent.

Despite the study of evidences of watershed degradation in Tanzania through soil erosion and sedimentation (Rapp et al, 1972), there still remains a void linking the effect of this degradation to streamflow at watershed scale. For example, the study by Rapp et al showed that four watersheds near Dodoma were degrading at different rates through reservoir sedimentation but they did not extend the study to see how the flow was affected in each catchment. Also the study by Temple, (1972) on Rufiji River hydrology and sediment transport showed that the watershed drained by this river was degrading as indicated by the 300 million tons of suspended sediment in 16 years, but the study could not answer the question why there was flow variability, that is due to watershed degradation or climatic changes.

The 5% probability of discharge was 1930 m^3/s, 3210 m^3/s, 2350m^3/s and 1390m^3/s in 1954/55, 1955/56, 1956/57 and 1957/58 respectively.

3. MATERIALS AND METHODS

3.1 Data Collection

3.1.1 Selection of study watershed and its physiographic characteristics

Selection of the study watershed was governed by availability of data. Mswiswi watershed was selected for more detailed study because it has long record of stream flow and precipitation data compared to other watersheds. Physiographic characteristics were obtain from topographical maps (1:50,000) covering Usangu Plains while soil data were collected through point auguring.

3.1.2 Selection of climatic stations and precipitation

Consideration was first given to locating climatic station with data that at least matched the period of record for nearby stream gauging stations. Emphasis was placed on finding stations which are preferably at higher elevation, and as close to the watershed served by selected stream gauging station as possible. Unfortunately, many of the stations that met this requirement were at lower elevations.

Irambo rainfall station which is near Mswiswi watershed was chosen to represent watershed average climatic conditions (Fig 1.1). This raingauge station was chosen on the basis of the following criteria: (1) It has precipitation data that have periods of record in common with the streamflow gauging station, (2) It is situated in upper of elevation which is within the watershed and its data were found to be homogenous.

Total monthly precipitation data from Irambo rainfall station used in this study is for water years 1960-1990 and was collected from the Directorate of Meteorology, Dar es Salaam.

3.1.3 Land use and erosion features

The primary source of information for determination of land use and erosion features were aerial photographs taken in 1977 (1:20,000) and topographical map of scale 1:50,000. On the basis of natural drainage, independent unit area of upstream of Mswiswi watershed has been delineated on the topographic map for measurement of land use and erosion features. The entire watershed is covered by about 7 panchromatic vertical photographs(10*10 inch). The photographs of the watershed were sorted out and the nominal photo scale was determined. Watershed boundaries were then stereoscopically delineated on the photographs by using 1:50,000 topographical maps of the survey of Usangu Plains as reference.

The land use and erosion features were then stereoscopically mapped from the central portion of the photographs directly on a piece of transparent overlay. Measurement of areal extent of land use and erosion features of the watershed was carried out by direct planimetering from the maps of 1977 and 1992 aerial photo interpretation.

The area of land use and gully measured in two maps were used to determine the rate of deforestation and gully expansion. The deforestation and gully expansion rate in

relation to forest and gully area was calculated using equation (1):

$$Deforestation/gullingrate(ha/y) = \frac{F_0 - F_2}{F_0 * N} * 100 \qquad (1)$$

Where, F_0 - forest or gully area at the beginning of reference period (1977)

F_N - forest or gully area at the end of reference period (1992),

N - number of years in reference period, N=15.

The forest or gully area at time, t, was calculated from equation (2):

$$F_t = F_0 - \sum_{0}^{t} \frac{F_N - F_0}{F_0 * N} * \Delta t \qquad (2)$$

Where, F_t - forest or gully area at time, t

Δt - time increment between periods under consideration.

3.1.4 Runoff and base flow

Stream flow has two components, i.e, runoff and base flow. Runoff is that portion of precipitation which does not infiltrate into the soil but flow over the surface until it reaches a channel. Base flow is represented by that portion of the precipitation which percolates deep into the soil and released slowly, sustaining stream flow during dry periods.Stream flow data used in this study are of record from 1960-1992.

Published and unpublished stream flow data were collected from Water Department - Ubungo, Daresalaam and from UVIP.

Regression and time series techniques were used to synthesize the missing streamflow data. To fix missing data, available flow data from stations in Mambi and Lunwa watersheds were correlated with flow data from Mswiswi gauge station by using equation (3) given by Raudkivi (1979):

$$Q_{iy}=Q_{mjy}+B_j(Q_j-Q_{mjx})+S_{jy}\sqrt{(1-r^2)}\varepsilon_i \qquad (3)$$

Where Q_{iy} and Q_{ix} are the discharge at stations y and x, respectively during the i^{th} month, Q_{mjy} and Q_{mjx} are the mean discharge at stations y and x respectively during the j^{th} month within a respective annual cycle of 12 months, B_j is the regression coefficient for y on x during he j^{th} month, S_{jy} is the standard deviation of discharge at y station during j^{th} month; r_j is the correlation coefficient between flows at stations x and y during the j^{th}; and e_i is the random variate assumed normally distributed with mean = 0 and standard deviation = 1.

Also in some of the cases equation (4) was used to synthesize the missing data (Raudkivi, 1979):

$$Q_i+1=Q_m(j+1)+B_j(Q_i-Q_{mj})+S_j+1\sqrt{(1-r_j^2)}\varepsilon_i \qquad (4)$$

Where Q_i and Q_{i+1} are discharges during i^{th} and $(i+1)^{th}$ month respectively, counted from the start of the generated sequence; Q_{mj} and $Q_{m(j+1)}$ are the mean monthly

discharges during the j^{th} and $(j+1)^{st}$ month respectively within annual cycle of 12 months, B_j is the regression coefficient for estimating flow in the $(j+1)^{th}$ month from the flow in the j^{th} month.

Runoff and baseflow data were obtained first by plotting monthly total water yield against time in order to get the monthly total water yield hydrographs. From monthly water yield hydrographs, monthly baseflow and direct runoff were separated. Separation was carried out by drawing a straight line from the point of rise to arbitrary point on the lower portion of the recession segment of the hydrograph. This arbitrary point was chosen to be at the end of May month, since according to rainfall records runoff is not expected in June because it is the end of rainy season.

3.1.5 Monthly watershed run curve number

Monthly watershed runoff curve number or hydrologic soil-cover complex is defined as a kind of runoff coefficient that has a relation to soil type and land use. The curve number is equivalent to potential maximum retention of the watershed. Watershed runoff curve number (CN) is an important indicator of watershed degradation since it reflects the antecedent moisture condition or storage of the watershed (Chow, 1964). Watershed storage decrease with increases of curve number (Raudkivi 1979). Monthly watershed curve number data for each water year of record was determined from equation (5) given by Park (1994)

$$CN=25400/(5P+10Q-\sqrt{(125PQ+100Q^2)}+254) \quad (5)$$

Where, Q - direct runoff (mm),

P - storm rainfall (mm).

By applying equation (5), monthly curve number data for each water year were generated.

3.1.6 Monthly watershed degradation factor

Watershed degradation factor is defined as a ratio of storm sediment yield to cropping and erosion control factor. Watershed degradation factor account for both vegetation cover and soil degradation through erosion. Monthly watershed degradation factor was determine from Revised universal soil loss equation (Edwards 1992):

$$Y_s=9.05*(Qq)^{0.56}*KLSCP \quad (6)$$

Where, Y_s - storm sediment yield (mg),

Q - storm runoff volume (m^3),

q_p - peak runoff rate (m^3/s),

K, LS, C and P are the RUSLE soil erodibility, slope,cropping and management and erosion control practice respectively.

The equation for estimating peak runoff, soil erodibility and length of slope has been defined in Appendix C. Modified soil loss can be written as :

$$\frac{Y_s}{CP}=9.05(Qq_p)^{0.56}*KLS \qquad (7)$$

In this study the left hand side of equation (7) is called watershed degradation factor (WDF): Therefore equation (7) can be written as:

$$WDF=9.05(Qq_p)^{0.56}KLS \qquad (8)$$

By running equation (8) through runoff data, soil data and watershed physiographical characteristics, monthly watershed degradation factors for each year of record were generated.

3.1.7 Monthly watershed loss factor (WLF)

Another important parameter considered by this study to be indicator of watershed degradation is watershed loss factor (WLF). Watershed loss factor is defined as a ratio of watershed loss to precipitation.

Although precipitation falling on a watershed may be held in storage on plants surface, in soil and bed rock, in lakes, it ultimately leaves the watershed as vapour.Though the processes of interception, direct evaporation and transpiration are

sufficiently different in conditions under which they occur, they all represent the same basic evaporation process. The evaporation process, therefore account for watershed loss. Watershed loss factor account for losses due to interception, evaporation and transpiration.

Increased streamflow is caused by reduction of water loss associated with vegetation through interception, evaporation and transpiration. Watershed loss factor was derived from water balance equation (Raudkivi, 1979) given as:

$$E=P-W-\Delta s \qquad (9)$$

Where E - Watershed loss,

P - Precipitation,

ΔS - Change in watershed storage,

W - Watershed yield.

Watershed loss include evapotranspiration and interception by vegetation cover. Assuming changes of storage, ΔS in a month period is very small, then equation (9) can be written as :

$$E=P-W \qquad (10)$$

Equation (10) can be written as:

$$\frac{E}{P}=1-\frac{W}{P} \qquad (11)$$

The ratio E/P, in this study has been named as watershed loss factor and it has been given the abbreviation 'WLF'. Therefore equation (11) is written as:

$$WLF=1-\frac{W}{P} \qquad (12)$$

By applying equation (12), monthly watershed loss factor data for each water year were obtained . Also applying equation (10), annual watershed loss for each year was calculated.

3.2 Data Analysis

3.2.1 Establishment of watershed degradation scenarios

In order to quantify the effect of watershed degradation on stream flow , it was necessary first to develop (establish) an adequate reference or basis for comparison i.e to establish pretreatment or calibration period and post calibration period. This has been accomplished by determining watershed degradation scenarios i.e to find the periods for which cumulative deficit (excess) of water yield is increasing or decreasing systematically over time. In other words to find the period for which the

water yield from the watershed is below or above the truncation level (long term average annual water yield). In order to distinguish watershed degradation scenarios of low flow from high flow, a truncation level (X_c) of water yield was first established. The period of time (number of consecutive years) for which cumulative deficit (excess) of water yield is systematically decreasing has been defined in this study as watershed degradation scenario of low flow. Otherwise for cumulative deficit which is systematically increasing has been considered as watershed degradation scenario of high flow.

Cumulative deficit (excess) of water yield is defined by equation(Lankeswara et al. 1991)

$$C_{de}=\sum_{0}^{t}(X_i-X_c) \qquad (13)$$

Where, C_{dc} - Cumulative deficit (excess),

X_i - Annual water yield of the year(i),

X_c - Truncation level.

3.2.2 Analysis of watershed degradation indicators

The overall objective of this part of analysis was to assess changes of watershed condition, to determine if existing land use practice degrades watershed condition. Changes of watershed condition were assessed by evaluating watershed degradation

indicators such as: ground cover condition, land use change, erosion features, watershed curve number, annual precipitation, watershed loss factor and watershed degradation factor. Trend analysis on annual precipitation, watershed loss and frequency analysis on monthly curve number, monthly watershed loss factor and watershed degradation factor were carried out as discussed in other subsections below.

3.2.3 Trend analysis of stream flow characteristics and watershed degradation parameters

In this analysis two types of trends were considered. The first is a trend in the central tendency of the data. If the average or median data value increase or decreases systematically over time, then this is a trend in the central tendency of the data distribution. Such trends describe the behaviour of average data overtime. The second type of trend considered is on the variability of the data with time. If data tends to become more or less variable with time, then the trend in variance is present. Both two types of trends were investigated by plotting the 5-year moving averages of the data series (annual water yield, annual base flow, annual runoff, annual precipitation and annual watershed loss) against time.

3.2.4 Frequency analysis

Frequency analysis of water yield, average monthly streamflow, monthly watershed curve number, monthly precipitation, monthly runoff, monthly baseflow, monthly watershed loss factor, and monthly watershed degradation factor for each watershed degradation scenario was carried out. The amount of work involved in frequency analysis was the preparation of flow duration curves. Frequency analysis was used to identify the difference among watershed degradation indicators and stream flow characteristics in watershed degradation scenarios. For comparison each parameter was plotted against probability of exceedance for four watershed degradation scenarios. Based on frequency analysis the decision rule indicating the effect of watershed degradation on stream flow was derived as follows:

Let T_0, T_1 .....T_N, be watershed degradation scenarios.

Let X_{b0p} and Y_{b0p} be random variables denoting watershed degradation indicator and stream flow of exceedance probability p, respectively in T_0, and let (X_{a1p}, Y_{a1p}); (X_{a2p}, Y_{a2p}); ...; (X_{aN}, Y_{aNp}) be watershed (degradation indicator, streamflow) of the same probability in T_1, T_2, ..., T_N, respectively. The decision rule is given as:

If $X_{b0p} < X_{a1p} < ... < X_{aNp}$ and $Y_{b0p} > Y_{a1p} > ... > Y_{aNp}$, and

If $X_{b0p} < X_{a1p} < ... < X_{aNp}$ and $Y_{b0p} < Y_{a1p} > ... > Y_{aNp}$, then there is a increasing and decreasing trend of runoff and baseflow, respectively from one scenario of low order to degradation scenario of higher order due to watershed degradation. The variable X denote watershed degradation indicator, i.e watershed storage, watershed loss factor and watershed degradation factor.

3.2.5 Model development

Models for evaluating the effects of watershed degradation were developed by using multiple linear regression. For each watershed degradation scenario, runoff and baseflow models were developed. Monthly runoff of given probability of exceedance was correlated with monthly precipitation the of same probability as runoff (Appendix H). Also monthly baseflow of given probability of exceedance was correlated with precipitation of the same probability as baseflow .

Data of Appendix H were fed in special program in Lotus to get regression models of runoff and baseflow respectively for each watershed degradation scenario. From individual runoff and baseflow models in each degradation scenario, general runoff and baseflow model was developed by regressing watershed coefficients for runoff and baseflow on time. The developed runoff and baseflow models were utilized to evaluate the effects of watershed degradation on streamflow. The models were run for equal rainfall event in each year to see how the watershed was responding or would respond to equal rainfall during the process of degradation. It has been assumed that if watershed is not degrading then watershed should respond the same runoff or baseflow for all years for the equal rainfall events.

4. RESULTS AND DISCUSSION

4.1 Watershed Degradation Scenarios

Cumulative deficit (excess) of water yield for each year has been given in Appendix I. By plotting cumulative deficit (excess) against time, four watershed degradation scenarios i.e 1960-65, 1965-75, 1975-86,and 1986-92 have been distinguished (Fig 4.1). The 1960-65 watershed degradation scenario has been taken as pretreatment of calibration period i.e the period for which there is relatively small watershed degradation and the other three scenarios are regarded as postcalibration period i.e after and during watershed degradation period.

In analysis of the data, all parameters of 1960-65 watershed degradation scenario are compared with other parameters in any of the three watershed degradation scenarios of interest (viz.1965-75,or 1975-86,or 1986-92). Fig 4.1 show that there was water deficit in 1960-65 and 1975-86 and water excess in 1965-75 and 1986-92 degradation scenarios. Sections below explains why there is cyclic trend of water yield from Mswiswi watershed as presented in Fig 4.1. The answer is given for example to the question: why there was water deficit and excess, respectively in 1960-65 and 1965-75?.

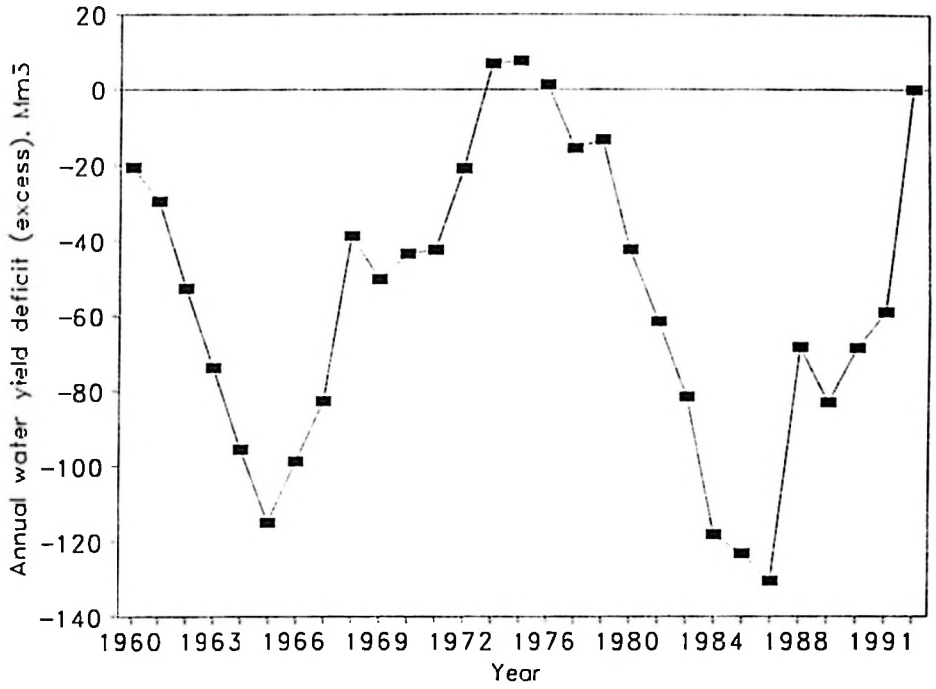

Fig 4.1 Watershed degradation scenarios: 1960-65, 1965-75, 1975-86, 1986-92

4.2 Watershed Degradation Evidences and Parameters

This was the first part of the analysis, which was to investigate if there is watershed degradation by evaluating the watershed degradation evidences and parameters. The parameters of watershed degradation analyzed are: precipitation, annual watershed loss, watershed loss factor, watershed curve number, watershed storage, and watershed degradation factor. Physical evidences analyzed are : dynamics of land use, gully expansion, sediment concentration and forest degradation.

The results of analysis of watershed conditions based on above parameters are presented in the subsections below.

4.2.1 Land use dynamics

Land use patterns as the main cause of watershed degradation were analyzed for Mswiswi watershed for the period 1977-1992. The expanding land use included agriculture and settlement which influences the two types of watershed degradation i.e soil erosion and deforestation.

Land use dynamics in Mswiswi watershed is presented in Table 4.1. Comparison of land use in Mswiswi watershed for the two periods 1977 and 1992 show that significant changes have occurred. The increase in area under cultivation from forest and arable virgin land has increased by 112.43 % and the area under settlements has increased by 15.62 %. Therefore, to a large extent the area which was under forest in 1977 has came under cultivation by 1992. Clearing forest and burning for agriculture could explain the extent of forest degradation and soil degradation through gully erosion.

Table 4.1 Land use dynamics in Mswiswi watershed

Culture	Area occupied in 1977, ha	Area occupied in 1992, ha	Change of land use,ha
1. Bareland or low grass vegetation	251.30	265.90	14.60
2. Mixed forest along the rivers and seasonal streams	952.00	794.40	-157.60
3 Scattered forest-open miombo woodland	1845.30	2030.30	185 .00
4. Forest reserve	75.30	27.40	-47.90
5. Low dense miombo woodland	1100.30	354.90	-745.40
6. Cultivated land(scattered and intensive agriculture)	1977.50	4200.90	2223.40
7. Scattered settlement	62.10	71.80	9.70
8. Burnt area	0.00	14.50	14.50
9. Cleared land	93.50	33.30	-60.20
10. Arable virgin land	2304.00	736.30	-1567.70
11. Alluvial bushed terminate mounts	10.30	34.80	24.50

4.2.2 Degree of forest Loss

There were four types of forest observed from aerial photographs of 1977 and 1992 in Mswiswi watershed (Table 4.1):

1. Mixed forest along rivers and seasonal streams in the dissected mountain ranges.
2. Riparian forest reserve in the moderately dissected mountain slopes.
3. Scattered forest (open miombo woodland)
4. Low dense miombo woodland in the mountain foot slopes.

The area occupied by the different types of forest have changed very much between 1977 and 1992. There is a decrease in area occupied by mixed forest, miombo woodland and riparian forest. However, there is an increase of area occupied by scattered open forest. This increase does not mean that there was no tree cutting for fuel and poles for construction but it is evidence that low dense miombo wood land

and forest reserve have been changed to more open forest.

The rate of forest loss can be deducted from Table 4.1. The rate of forest loss for 15 year period was 10.5, 3.2 and 49.7 ha/year for mixed forest, forest reserve and low dense miombo wood land, respectively. The rate of forest loss is highest for miombo wood land followed by mixed forest. The average rate of forest loss is 21.13 ha/year. Based of this rate of forest loss, the change of forest area was predicted (Fig 4.2). Fig 4.2 show that in 1998 the forest area will be 1683.87 ha, this is a decrease of forest cover by 21 %. Fig 4.2 show that gully expansion is increasing as forest cover decreases.

The rate of soil and gully expansion changes with human population changes, changes in technology and environmental awareness. Therefore it is rare to find straight line as in Figure 4.2. However, for the purpose of this study it has been assumed that it is static because data were adequate.

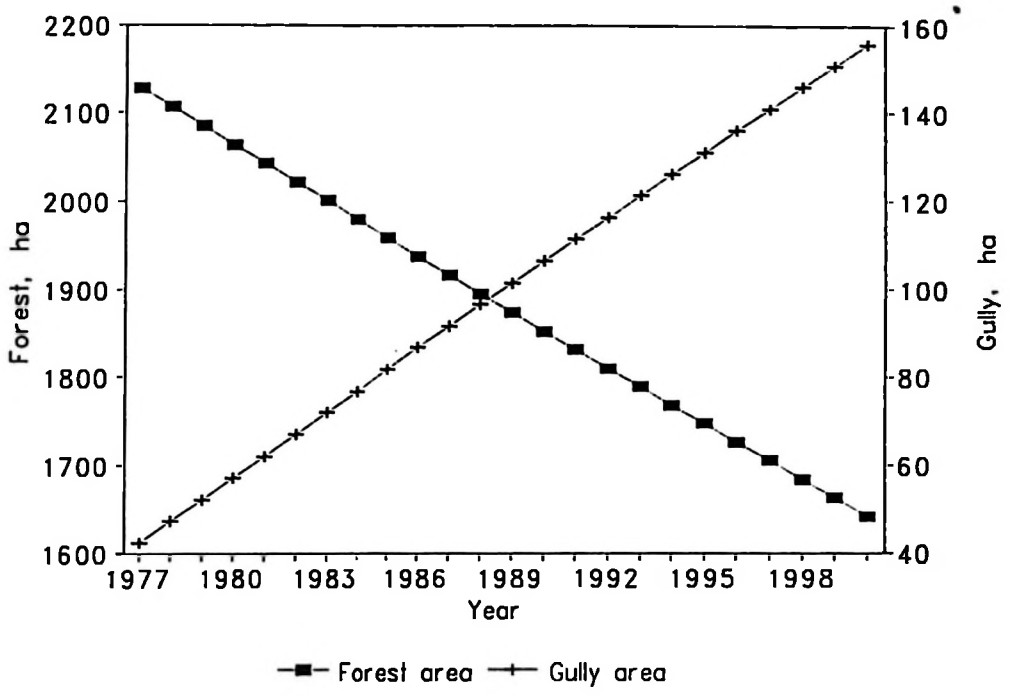

Fig 4.2 Change of forest and gully area at Mswiswi watershed

4.2.3 Watershed soil degradation

Evidence of watershed soil degradation was seen through comparison of area occupied by gullies in two periods 1977 and 1992 (Table 4.2) determined by intrepretation from aerial photos and presence of suspended sediments in the river (Table 4.3). For 15 years, small and very deep gullies in Mswiswi watershed were expanding at rate of 4.93 ha/year.

Table 4.2 The area covered by gullies in Mswiswi watershed

Year	Area occupied, ha	% watershed eroded
1977	42.40	0.49
1992	116.30	1.34
Gully expansion	73.90	0.85

Table 4.3 Suspended sediment load in Mswiswi river

Sampling date	Sediment load, (g/s)
2/2/1996	45.25
9/2/1996	32.62
16/2/1996	78.65
28/2/1996	33.31
16/3/1996	39.34
26/3/1996	485.48
Mean	119.11

4.2.4 Trend of annual precipitation and annual watershed loss

Long period trends in distribution of annual precipitation and watershed loss was investigated through 5- year moving averages of precipitation and watershed loss. The precipitation and watershed loss data used to calculate 5-year moving averages are presented in Appendices A and B. The use of 5-year moving averages of precipitation and watershed loss values to investigate watershed degradation is shown in Fig 4.3 and Fig 4.4 respectively. Fig 4.3 and Fig 4.4 show that there is systematic decrease of annual precipitation and watershed loss with time. The decrease of these two parameters shows that there is watershed degradation, first since the reduction of watershed loss is associated with vegetation cover through intercept and evapotranspiration. Second, the gradual decrease of precipitation is also an indicator of deforestation because of influence of vegetation on hydrologic cycle.

Results of frequency analysis of monthly precipitation for four watershed degradation scenarios has been presented in Table G_1 through Table G_1 of Appendix G. Fig 4.5 shows the comparison of monthly precipitation among degradation scenarios for selected probabilities. Fig 4.4 show that there was decreasing trend in monthly precipitation from one watershed degradation scenario of lower order to watershed degradation scenario of higher order for all probability of exceedance, i.e monthly precipitation of given probability of exceedance for 1960-65 scenario was greater than monthly precipitation of 1965-75 scenario.

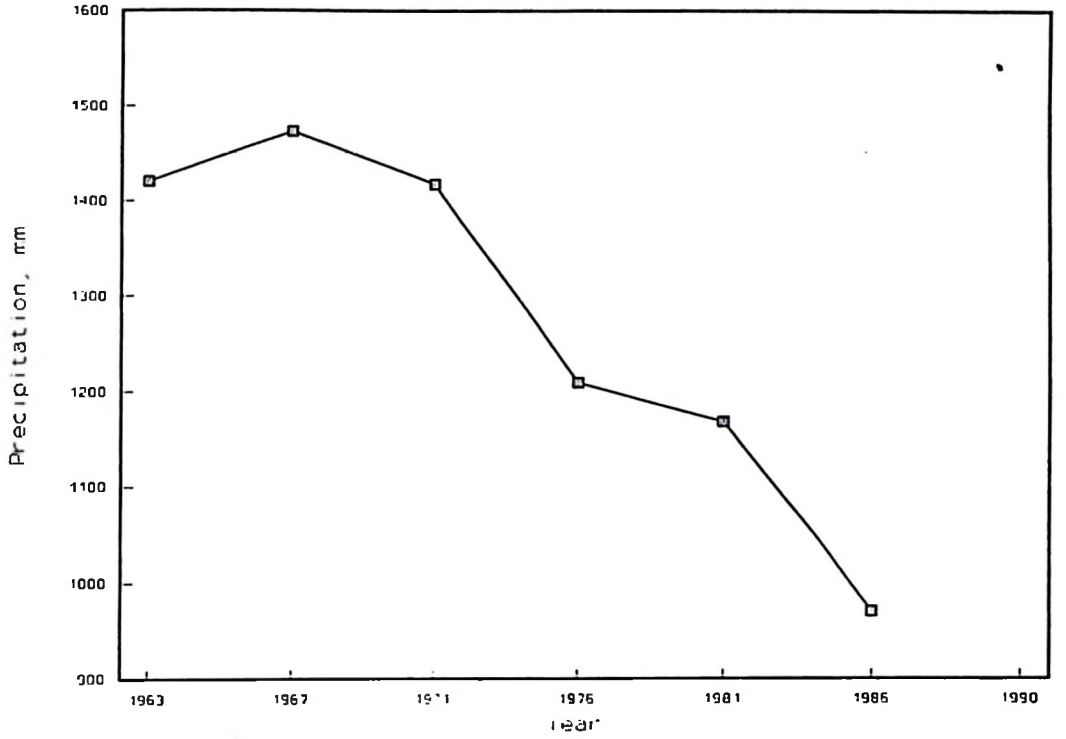

Fig 4.3 Trend of 5-year moving average of annual precipitation

Fig. 4.4 Trend of 5-year moving average of annual watershed loss

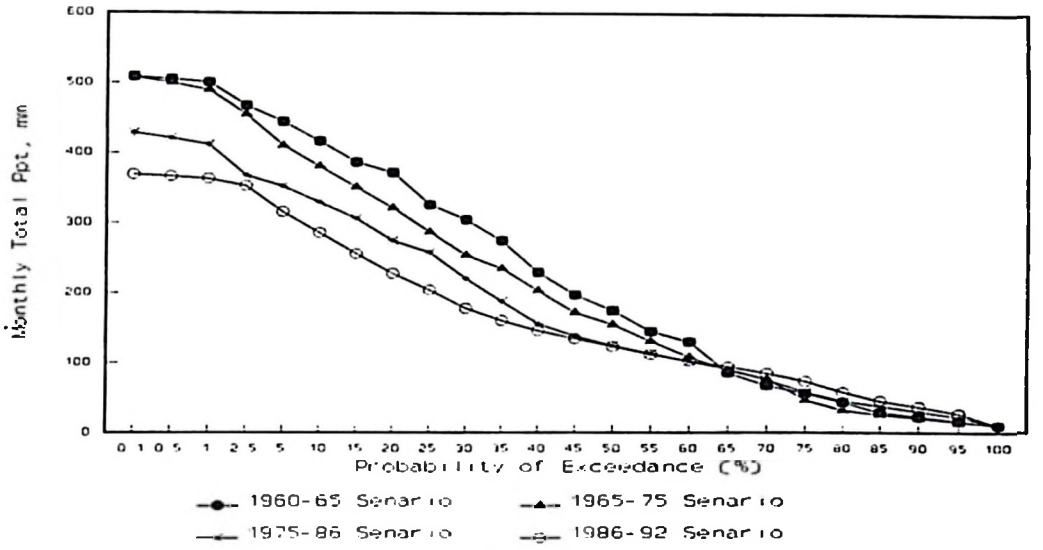

Fig 4.5 Comparison of monthly precipitation in four watershed degradation scenarios

For 10% probability there was a decrease of precipitation by 146.17, 180.31, 223.67mm in 1965-75, 1975-86 and 1986-92 respectively compared to precipitation of the same probability in 1960-65 scenario.

4.2.5 Watershed curve number and storage

The calculated monthly curve number for each year of record has been represent in Table D_2 of Appendix D. Based on this data frequency analysis was performed for each watershed degradation scenario. The results of frequency analysis of monthly curve number for each watershed degradation scenario are shown in Appendix G.

The comparison of curve numbers for four watershed degradation scenarios is shown in Fig 4.6. Fig 4.6 shows that for a given probability of exceedance less that 80 % the curve numbers in 1960-65 degradation scenario were always lower compared to other three degradation scenarios. Lower curve number in 1960-65 scenario indicated that deforestation was low in that period compared to the other three. Curve numbers in 1965-75 and 1975-86 scenarios were morales the same but comparatively they were lower compared to curve numbers in 1986-92 degradation scenario. There was an increase of curve number by 17.75, 23.66 and 26.13 in 1965-75, 1975-86 and 1986-92, respectively compared with curve number of 1960-65 degradation scenario for 10 % probability of exceedance. This increase of curve number correspond with the decrease of watershed storage by 66.4 mm, 83.14mm and 89.55mm in 1965-75, 1975-86 and 1986-92 degradation scenarios respectively (Fig 4.7).

For a given probability of exceedance watershed storage was decreasing with time from watershed degradation scenario of lower order (1960-65) to degradation scenario of higher order, i.e 1986-92 (Fig 4.7). Fig 4.7 show that for wet season i.e 10% probability of exceedance monthly watershed storage was 89.2 mm, 22.8 mm, 6.06mm and 0 mm in 1960-65, 1965-75, 1975-86 and 1986-92 watershed degradation scenario and for dry seasons i.e 80% probability monthly watershed storage was 715.46 mm, 634.11 mm, 602.08 mm and 448.82mm in 1960-65, 1965-75, 1975-86 and 1986-1992 respectively.

This trend of decrease in monthly watershed storage indicate that there was decrease of vegetation cover to retain precipitation for infiltration.

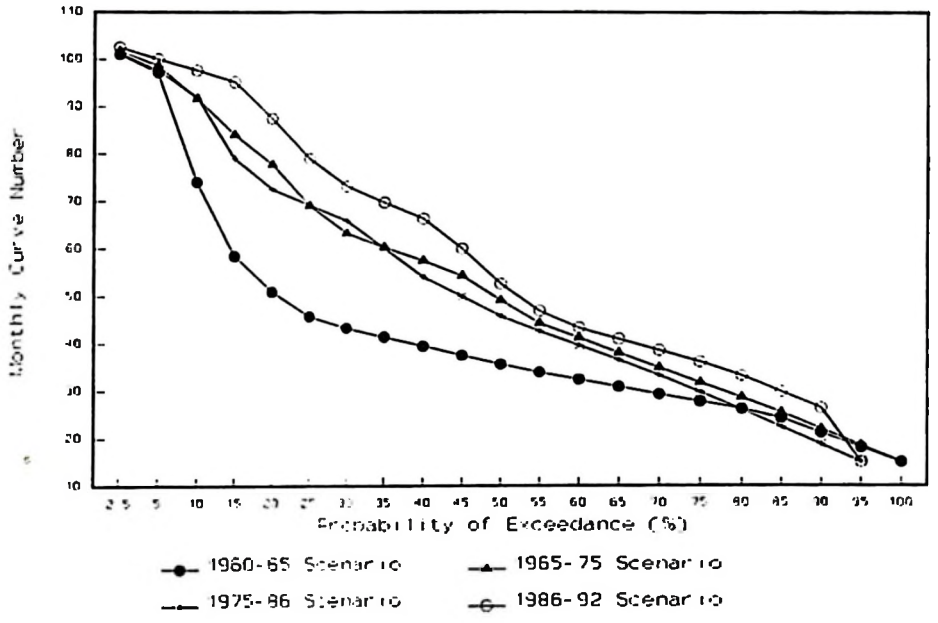

Fig 4.6 Comparison of monthly curve number in four watershed degradation scenarios

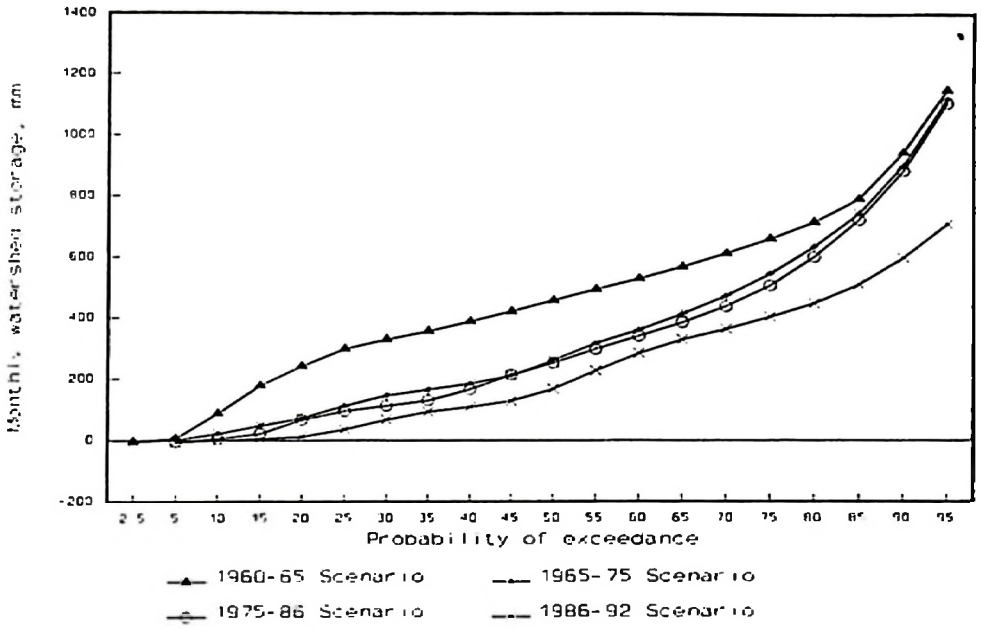

Fig 4.7 Comparison of monthly watershed storage in four watershed degradation scenarios

4.2.6 Watershed loss factor

Computed monthly Watershed loss factor data has been presented in Table B_2 of Appendix B and frequency analysis based on those data for each degradation scenario has been given in Appendix G. Fig. 4.8 represent the comparison of monthly watershed loss factor for four watershed degradation scenarios for selected probability of exceedance of monthly watershed loss factor. Fig 4.8 show a decreasing trend of monthly watershed loss factor from watershed degradation scenario of lower order towards the watershed degradation scenario of higher order.

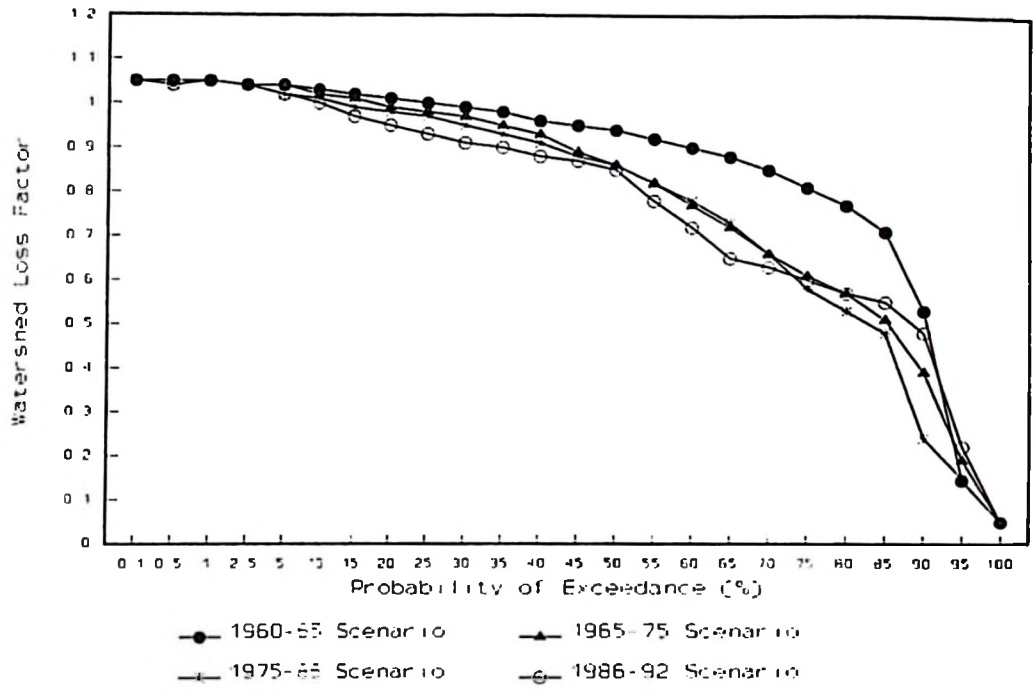

Fig 4.8 Comparison of monthly watershed loss factor (WLF) in four watershed degradation scenarios

Since watershed loss factor accounts for watershed loss by vegetation through evapotranspiration and interception, the decrease of watershed loss factor with time indicate that there is watershed degradation due to the decrease in vegetation cover (deforestation). Watershed loss factor(WLF) was almost constant in both watershed degradation scenarios for probability of exceedance <25% (Fig 4.8). This is due to the fact that probability of exceedance <25% corresponds to wet season where the watershed vegetation cover is improving for all scenarios because of grass growth. Comparison of watershed loss factor of 1960-1965 watershed degradation scenarios with 1965-75, 1975-86 and 1986-92 watershed degradation scenarios shows that there was decrease of watershed loss factor for all conditions of watershed expressed by probability of exceedance. For 80% probability watershed loss decreased by 0.2,

0.24, 0.2 in 1965-75, 1975-86 and 1986-92, respectively, compared with watershed loss factor of 1960-65 for the same probability. The decrease in this factor indicates losses due to evapotranspiration and interception resulting from less vegetation cover.

4.2.7 Watershed degradation factor

Physiographic characteristics of the watershed used in determining watershed loss factor are presented in Table 4.4. The result of computed monthly watershed degradation are presented in Table G_2 of Appendix G .

Table 4.4 Physiographic characteristics of Mswiswi watershed

Parameter	Value
Watershed area (km_2)	87.05
Watershed width (m)	23750.00
Mean slope of the watershed	4350.00
Stream bed slope	0.06
Drainage density (m/km_2)	0.04
Channel length (m)	261.00
Soil texture	29750.00
- silt %	30.00
- sand %	46.00
- clay %	24.00
- organic carbon %	1.48
- textural class	CL

Frequency analysis of watershed degradation factor for the four degradation scenarios has been presented in Appendix G. Comparison of watershed degradation factor for four degradation scenarios is presented in Fig.4.9

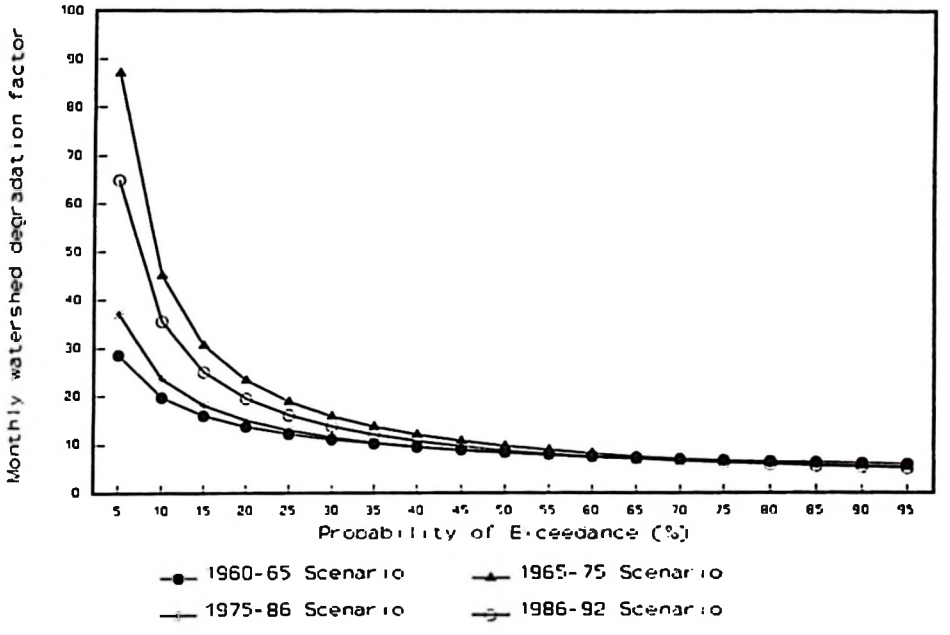

Fig 4.9 Comparison of watershed degradation factor (WDF) in four watershed degradation scenarios

Figure 4.9 show that there was a systematic trend of increase of watershed degradation factor from degradation scenario of lower order to degradation scenario of higher order for all probability of exceedance less than 45% except for 1965-75 scenario where it was found that it is higher than the other three scenarios . Since watershed degradation factor is a ratio between sediment yield and vegetation factor, therefore increase of watershed degradation factor indicates an increase in the area vulnerable to soil erosion.

Fig 4.9 show that watershed degradation factor was a random variable but watershed degradation factor of 1960-65 scenario was less compared with other three degradation scenarios for all severe conditions of degradation i.e for probability less than 40%. For severe condition of degradation i.e 10% probability of exceedance, for instance, there was an increase of watershed degradation by 25.24, 3.83, and 15.80 in 1965-75; 1975-86 and 1986-92, respectively compared with watershed degradation scenario in 1960-65.

4.3 Effect of Watershed Degradation on Streamflow Characteristics

The streamflow characteristics analyzed were annual water yield, runoff and baseflow. The results of the analysis are presented below.

4.3.1 Annual water yield and runoff

Plots of 5-year moving averages of annual water yield and runoff against time are shown in Fig 4.10 and Fig 4.11, respectively.

The 5- year moving average of annual water yield and runoff (Fig 4.10 and Fig 4.11) shows that there was variability in annual water yield and runoff. The variability of annual water yield and runoff increased from 1963 until about 1971, then decreased from then to 1983, and increased from there through the end of record. The main issue here was therefore to give the answers to questions: why runoff and water yield

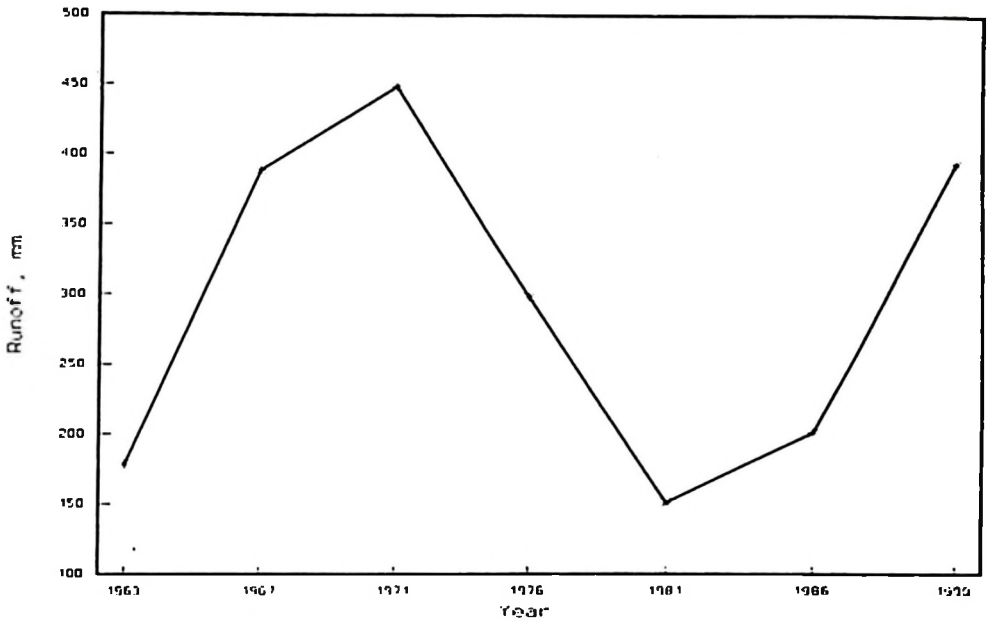

Fig 4.10 Trend of 5-year moving average of annual runoff from Mswiswi watershed

was increasing or decreasing for some periods? Are these changes caused by watershed degradation or they are consequences of climatic variations ?

Existence of water deficit or excess (Fig 4.1) period in the Mswiswi watershed was due to combined effect of climatic changes and watershed degradation processes on streamflow and it depend on which process is dominating. For example in 1960-65 scenario average annual rainfall and runoff was 1420.3 and 208.1 mm, respectively and in 1986-92 rainfall and runoff was 678 and 246 mm, respectively. This show that the excess water yield was due to forest degradation otherwise if it was not the case, runoff could have decrease as there was decrease of average rainfall in 1986-92

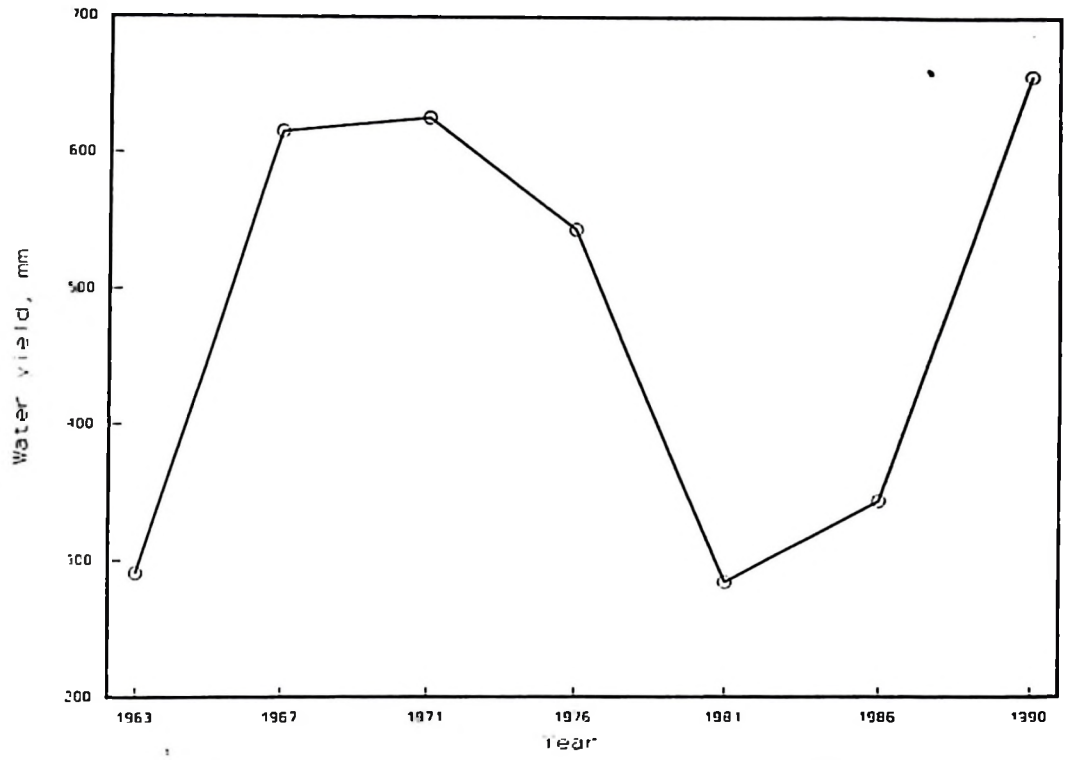

Fig 4.11 Trend of 5-year moving average of annual water yield from Mswiswi watershed

degradation scenario compared to 1960-65 scenario. There was a combined effect of climatic changes and watershed degradation on streamflow in 1965-75 degradation scenario. Average rainfall and runoff in 1965-75 was 1449 and 421 mm, respectively.

Since watershed was degrading in 1965-75 and there was increase of rainfall compared with 1960-65 scenario, therefore increase of average annual runoff by 213 mm was due to watershed degradation and an increase of rainfall by 28,5 mm. In 1975-86 scenario effect of climate changes on streamflow was dominating or exceeding the effect of watershed degradation on streamflow. Although there was watershed degradation in 1975-86, but its effect was not significant compared to

effect caused by decrease of average annual rainfall by 419 mm compared to rainfall in 1960-65 scenario. Average annual rainfall and runoff in 1975-86 scenario was 1001 and 190mm, respectively. Comparison of monthly runoff in four watershed degradation scenarios (Fig 4.12) show that there is a systematic trend of increasing monthly runoff of given probability of exceedance from 1960-65 scenario to 1986-92 scenario. If the mid year for each scenario is taken, we can deduce that there was a systematic increase of runoff of probability of exceedance less than 40% from 1963 to 1989. For example runoff has increased by 30.31, 73.24, 104.46mm in 1965-75, 1975-86 and 1986-92 watershed degradation scenario respectively for 10% probability compared with 10% runoff in 1960-65 degradation scenario. This increasing trend of runoff from degradation scenario of lower order (1960-65) to scenario of higher order (1986-92) corresponds to decreasing trend of watershed storage (Fig. 4.7) and watershed loss factor (Fig 4.8).

Runoff of 10 % probability was compared with watershed degradation indicators in order to see the effect of watershed degradation on runoff (Fig 4.13). Runoff of 10 % probability was chosen for this comparison because most of water structures are designed for safety based on 10% probability of runoff. Therefore, there was a need to see how watershed degradation affects this runoff because always in designs it is assumed that the magnitude of this runoff doesn't change after 10 years recurrence interval. Watershed storage, watershed curve number, watershed curve number, watershed loss factor and watershed degradation factor of 10 % probability are watershed degradation indicators of which runoff of 10 % probability was compared

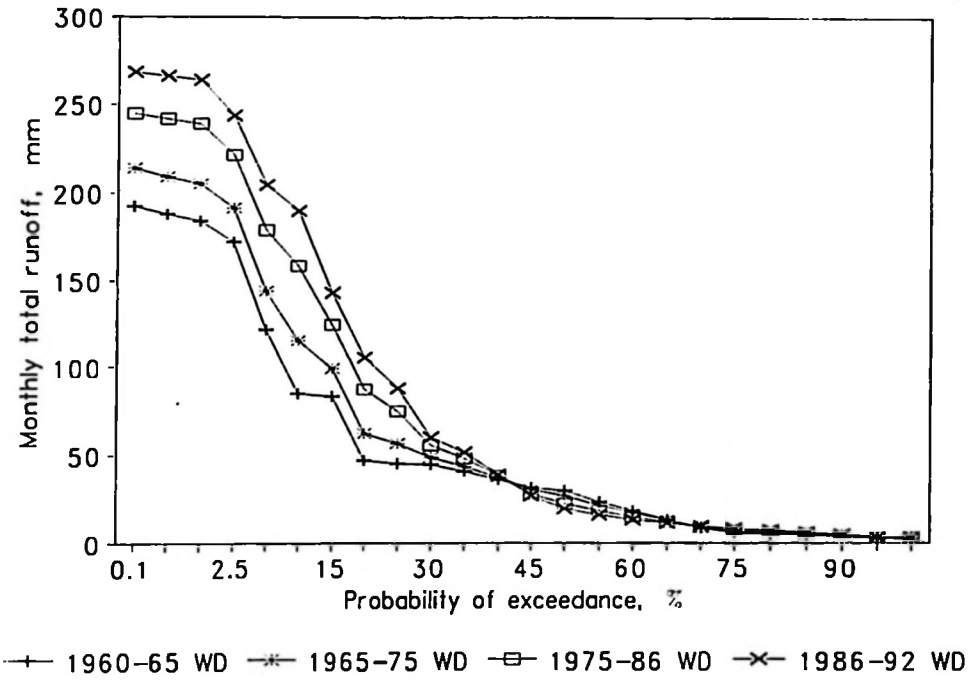

Fig 4.12 Comparison of monthly runoff in four watershed degradation scenarios

with (Fig 4.13 and 4.14).

Fig. 4.13 show the effect of watershed degradation as indicated by watershed storage, watershed curve number, watershed degradation factor on 10% probability of runoff. The trend of increase of 10% probability of runoff was following the trend of change of watershed degradation indicators. For example runoff was increasing as per decrease of watershed storage and as per increase of curve number. Watershed storage and curve number is associated with vegetation cover. Watershed storage decreases with decrease of vegetation cover. Vegetation cover was decreasing with

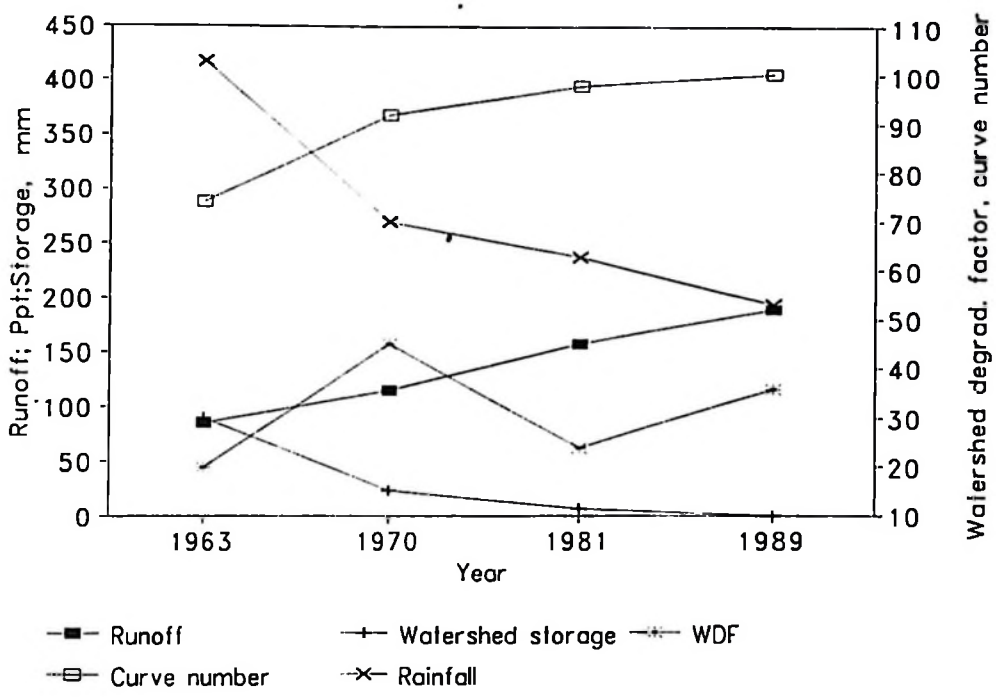

Fig 4.13 Comparison of trend of runoff of 10% probability with watershed degradation indicators and rainfall

time as indicated through watershed forest degradation (Fig 4.2). Fig 4.13 show that trend of 10% probability of runoff was not following exactly the cyclic trend of watershed degradation factor and therefore watershed degradation factor was not good criteria to use in evaluating the effect of watershed degradation on runoff.

Runoff of 10% was increasing as rainfall of 10% probability was decreasing (Fig 4.13). With decrease of precipitation we could expect the decrease of runoff, but this was not the case. Runoff of 10 % probability was increasing with time because of

watershed degradation as indicated by decrease of vegetation cover (Fig 4.2) and increase of drainage density through gully expansion (Fig 4.2).

Effect of watershed degradation on runoff was evaluated also by comparing runoff of 10% probability with watershed loss factor of 10 % probability (Fig. 4.14). Runoff was increasing as the watershed loss factor was decreasing. The decrease of watershed loss factor correspond to decrease of losses through evapotranspiration and interception by vegetation. This indicate that the capability of the watershed to retain rainfall is decreasing.

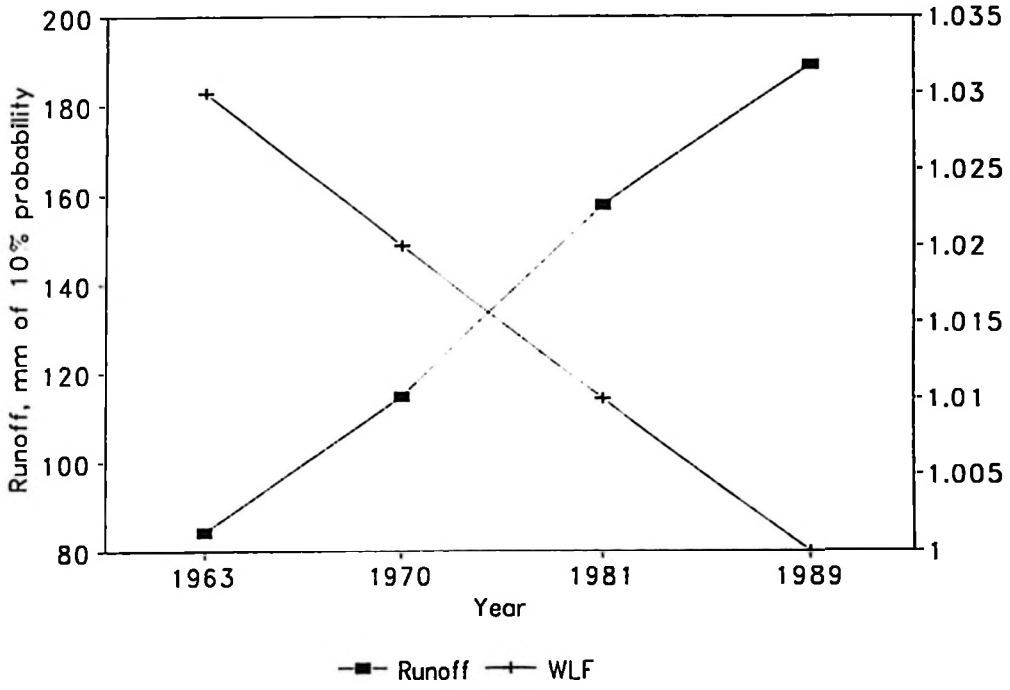

Fig 4.14 Effect of watershed degradation as indicated by 10% probability of watershed loss factor on 10% probability of runoff

The results of this study show that there are two processes in Mswiswi watershed namely, watershed degradation and climatic changes. Both processes affect streamflow. Comparing Figs 4.10 and 4.11 with Figs 4.3 and 4.4, shows that the increase in water yield and runoff was partly due to increase in precipitation as a climatic factor and decrease of watershed loss (evapotranspiration and interception) as indicator of watershed degradation. However, the decrease in water yield and runoff was due to the effect of climate alone. Therefore the effect of watershed degradation alone on streamflow can not be seen clearly without isolating the effect of climatic factors (precipitation and evaporation) on streamflow. To assess the effect of watershed degradation alone, runoff model for each watershed degradation scenario was established (Table 4.5).

Table 4.5 Results of regressing monthly runoff (Q) of given probability of exceedance on monthly precipitation (P)of the same probability as runoff for four Mswiswi watershed degradation scenarios

Watershed degradation scenario	Regression Equation	r^2	Std. Err of Q.est
1960-65	$Q=0.078P^{1.166}$	0.94	0.16
1965-75	$Q=0.085P^{1.192}$	0.95	0.14
1975-86	$Q=0.036P^{1.404}$	0.93	0.19
1986-92		0.87	0.24

$$Q=0.019P^{1.555}$$

These models are not predictive but are indicatives models which enables us to detect existing difference of watershed characteristics in each watershed degradation scenario. Due to watershed degradation, watershed condition was changing with time from one scenario to another.

Table 4.5 show that although the watershed was the same, watershed characteristics were changing with time, hence equations in the different scenarios was changing. If watershed characteristics were constant we could have got the same equation for all watershed degradation scenarios. The process of watershed degradation affect the watershed characteristics which affect runoff yield from the watershed and that could be the reason for equation difference.

Watershed characteristics which affect runoff are grouped as climatic factors and physiographic factors. Physiographic factors which change with degradation scenarios are land use and drain density through gully expansion.

Although runoff is expressed by different equations according to existing watershed characteristics in each degradation scenario, all the models can be expressed generally by the equation:

$$Q=aP^{b} \qquad \textbf{(18)}$$

Where, Q -monthly runoff, mm of given probability,

P -monthly precipitation total, mm

a, b -watershed parameters accounting for changes in watershed characteristics affecting runoff.

As indicated in Table 4.5, watershed parameters (a and b) for runoff were varying with time due to watershed degradation which was ultimately affecting watershed characteristics. Watershed parameter (a and b) for runoff was (0.078,1.166), (0.085,1.192), (0.036,1.404) and (0.019,1.555) in 1960-65, 1965-75, 1975-86 and 1986-92, respectively. The equations expressing these parameters were obtained through regression analysis and the resulting equations are given by:

$$a=0.097e^{-0.058t} \quad (19)$$

$$b=1.137e^{0.012t} \quad (20)$$

The regression coefficient was 0.95 and 0.98 for a and b, respectively. The general runoff model was obtained by substituting a and b in equation (18). The resulting general runoff-precipitation model is then given by :

$$Q=0.097e^{-0.058t}P^{1.137e^{0.012t}} \quad (21)$$

Where, Q - monthly total runoff , mm

P - monthly total precipitation, mm

t - time in years in reference period from 1963.

The general runoff-precipitation model was calibrated using the April (month) data of year of record. The data input to this model were monthly precipitation and monthly runoff separated from total streamflow. Model residuals (observed runoff minus modeled runoff) were analyzed to visualize the observed errors. Comparisons of the observed and modeled runoff show that the data are in good agreement (Fig 4.15). There was no significant difference at 95 percent confidence level between the means of observed and simulated runoff as $t = 0.83 < t^{46}_{0.025} = 2.02$ (Appendix K).

Since the runoff model incorporate both watershed degradation and climatic factors, it is not easy to identify from Fig 4.15 which period of the record runoff was affected by watershed degradation and which of the period runoff was affected by climatic factors. To evaluate the effect of watershed degradation on runoff, precipitation was isolated from the model by keeping it constant for all years of record. The logic in this assumption is to observe how the watershed would have responded to equal rainfall under different conditions agitated by degradation of watershed. It has been assumed that if Mswiswi watershed was not degrading it should yield the same runoff in every year of record for the same rainfall event. When precipitation is kept constant, the only changing factors which affect runoff remain to be physiographic

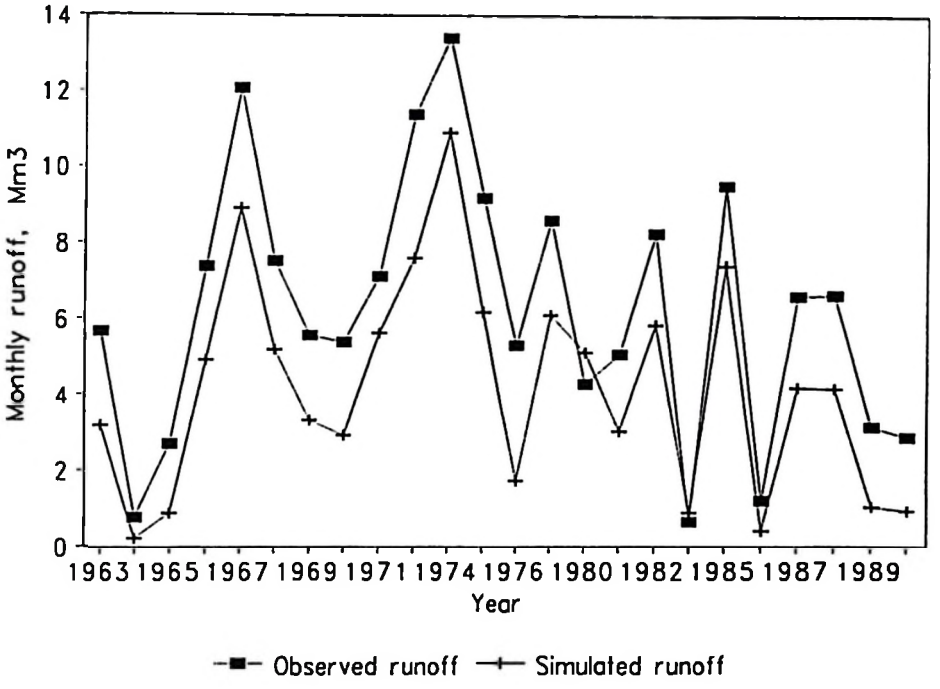

Fig 4.15 Comparison of observed and modelled total runoff in April month for period from 1963-1989

factors which are affected by watershed degradation.

By running the model for equal rainfall in each year, monthly runoff was calculated for every year. The plot of calculated runoff against time is presented in Fig 4.16. The figure show that runoff was decreasing for rainfall $p <= 10$mm and increasing for all rainfall $p > 10$mm as watershed was degrading. For example, if 100mm rainfall had fallen in 1963 the response of the watershed would have been 18.23mm of runoff but if the same rainfall will happen to reoccur in the year 2000, the response of the watershed would be 39.79mm of runoff (Fig. 4.16).

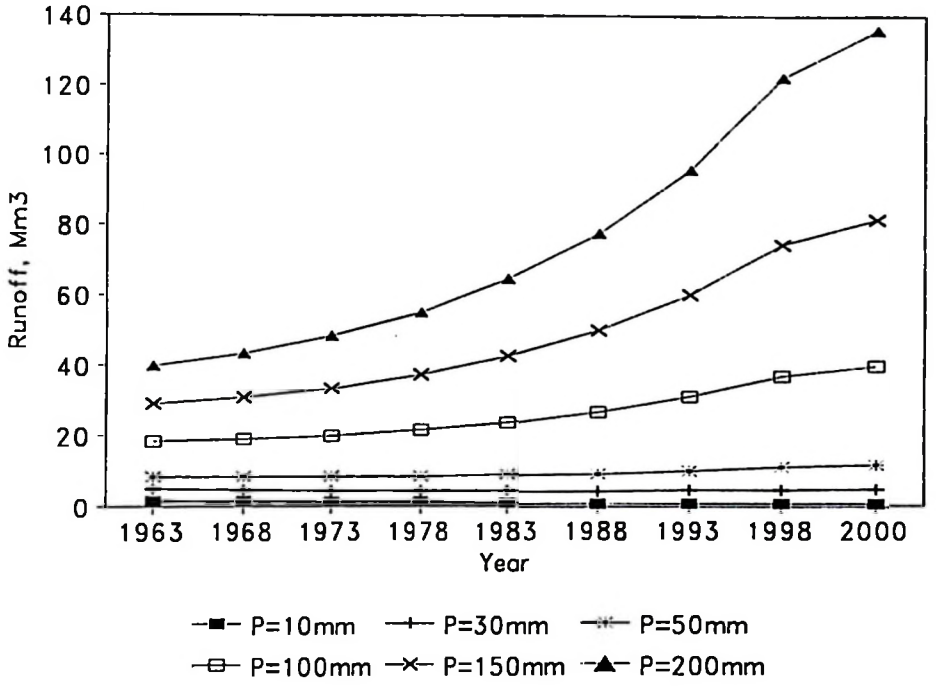

Fig 4.16 Simulated monthly runoff response of Mswiswi watershed to equal rainfall events

4.3.2 Base flow

Results of separation of stream flow into base flow and runoff has been presented in Table F_4 and Table F_6 of Appendix F. Base flow variability was investigated by plotting 5-year moving averages of annual baseflow against time (Fig 4.17). Fig 4.17 shows that there was variability of baseflow of a gentle upward trend from 1963 until 1967 and has risen sharply till 1976 and from then has decreased until 1981 and then upward trending until the end of its record. Decrease of base flow in Mswiswi watershed means less water is available for withdrawal at succeeding dates while

variability of baseflow leads to decrease of length of time during which water can be withdrawn (Barringer 1994).

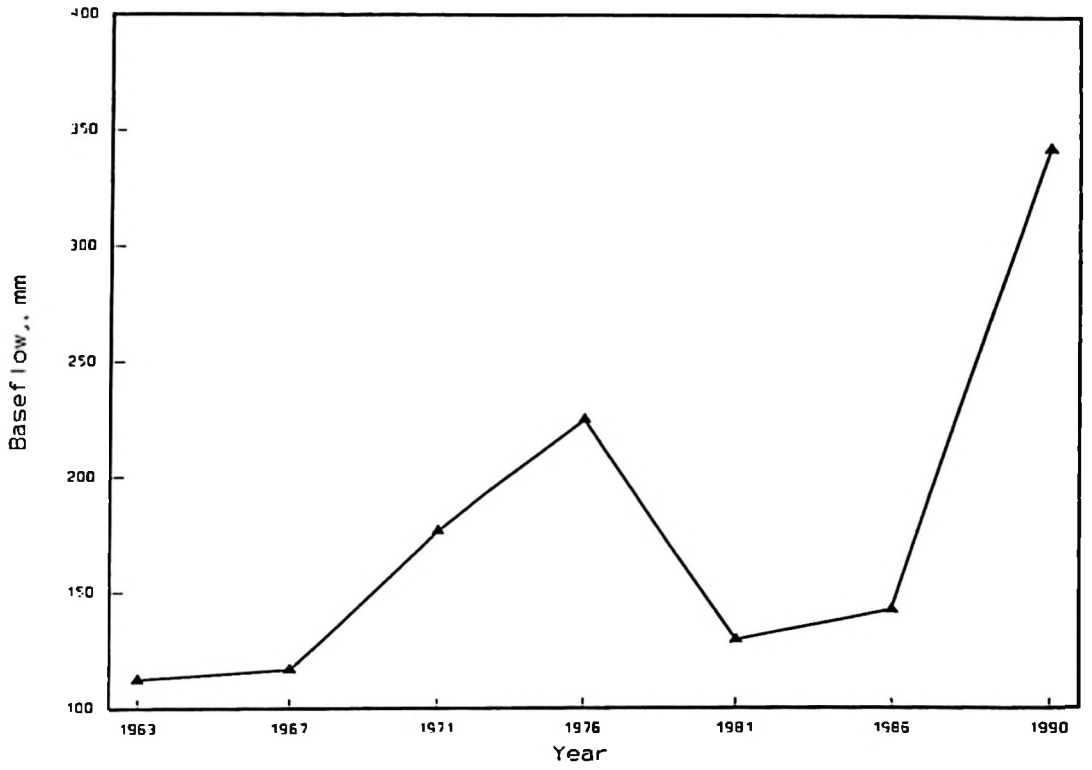

Fig 4.17 Trend of 5-year moving average of annual baseflow from Mswiswi watershed

4.3.2.1 Base flow variability with watershed degradation scenario

Comparison of baseflow of given probability of exceedance for the four degradation scenarios (Fig 4.18) shows that baseflow of given probability of exceedance in 1960-65 was lower compared to the other three watershed degradation scenarios, i.e, 1965-75, 1975-86 and 1986-92. There was cyclic trend of baseflow for all probability of exceedance. For example, for 80% probability, baseflow was 5.10, 5.81, 5.2 and 7.94 in 1960-65, 1965-75, 1975-86 and 1986-92 watershed degradation scenario

(WD) respectively. This cyclic trend of baseflow variability could be due to combined effect of watershed degradation and change of climatic factors.

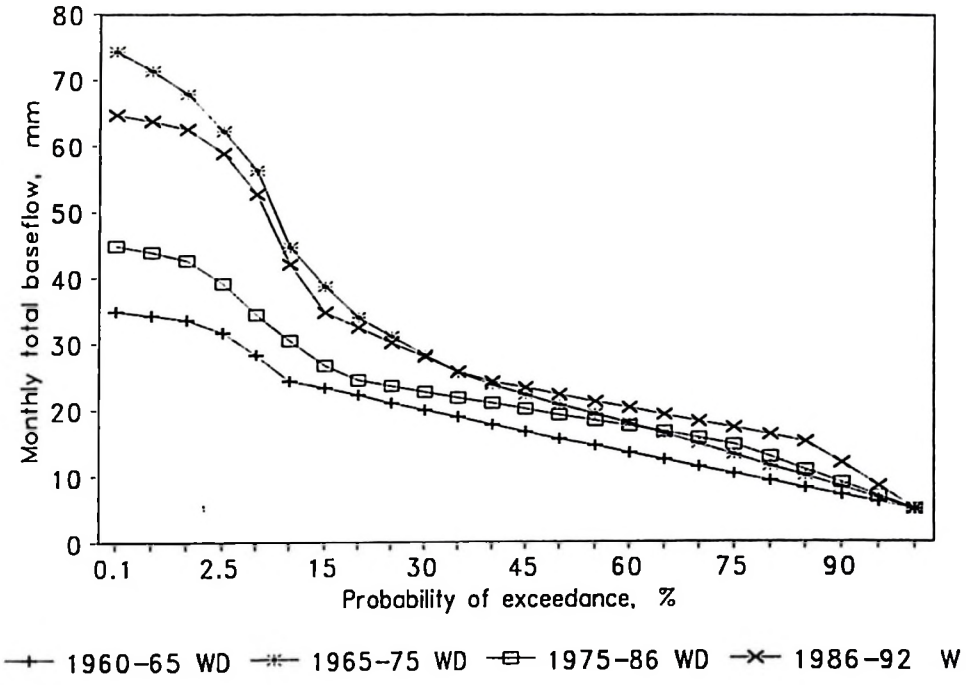

Fig 4.18 Comparison of monthly total baseflow in four watershed degradation scenarios

4.3.2.2 Variability of base flow with watershed degradation indicators

In relating baseflow characteristics with watershed degradation factors, the main question is: what was the cause of baseflow variability?, i.e why for example, an increasing trend of annual base flow in 1963-1976 and decrease in 1976-81? (Fig 4.17), or why was the baseflow of a given probability in 1965-75 degradation scenario higher than in other three; was it because of climatic changes? or was it

because of watershed degradation changes?.

Since there was a systematic decreasing trend in precipitation with time (Fig 4.3 and Fig 4.4) we could expect a decreasing trend in baseflow. But, comparison of Figs 4.17 and 4.18 with Figs 4.3 and 4.6 shows that, trend of baseflow didn't follow exactly the trend of precipitation. Comparison of trend of baseflow variation of given probability with trend of variations of watershed degradation indicators shows that cyclic trend of baseflow is more related to cyclic trend of watershed degradation factor (Comparison of Fig. 4.18 with Fig. 4.9). For example Fig. 4.19 represent the trend in which baseflow was changing as compared to watershed degradation factor for probability less or equal 60 %. Baseflow was increasing and decreasing with time as watershed degradation factor increasing and decreasing, respectively. The explanation for this phenomena is not easy since baseflow is the results of many interacting factors. But one of the explanations for variation of baseflow with watershed degradation factor could be the effect of components of watershed degradation factor.

One of the components of watershed degradation factor is runoff which is affected by physiographic characteristics (land use and drainage density) and precipitation in the watershed. The decrease in forest cover and increase of drainage density observed in this study, influences the increase in runoff, and hence the increase of watershed degradation factor. Also increase of drainage density through gully expansion enables interception of ground water by gully channels which are connected to the river. The

gully flows may contribute to the rise in baseflow. The decreasing trend of precipitation for some periods contribute to the decrease of both baseflow and watershed degradation factor.

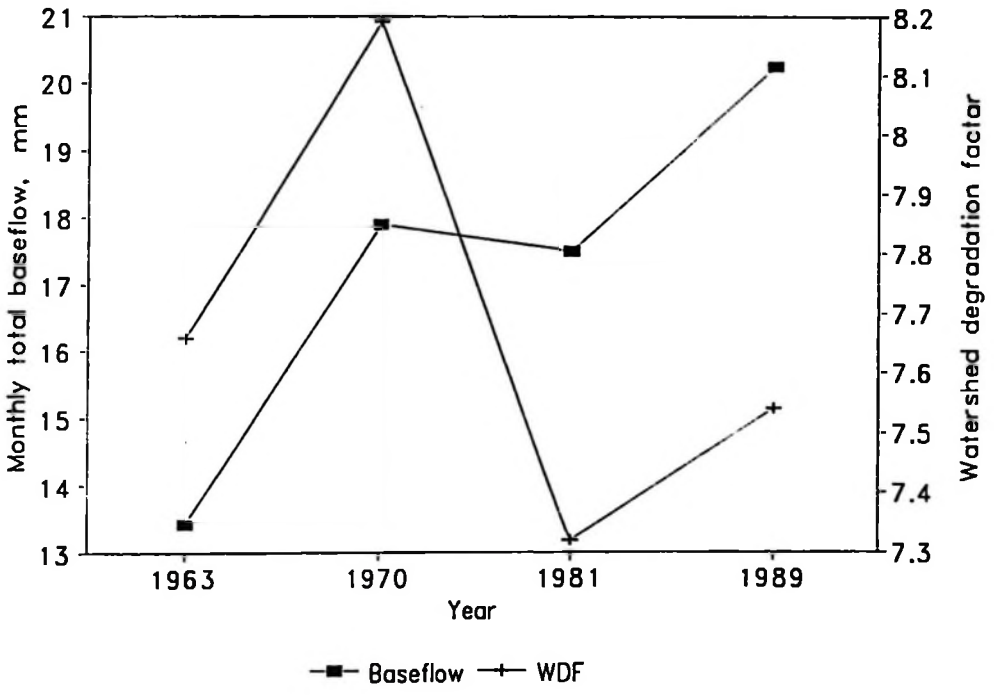

Fig 4.19 Comparison of trend of baseflow with watershed degradation factor for 60% probability of exceedance

4.3.2.3 Baseflow model for evaluation of effects of watershed degradation on baseflow

Results of comparison of baseflow with climatic factors,i.e precipitation and watershed degradation indictors shows that baseflow was both affected by climatic factors and watershed degradation. The results contradict when comparing variation of baseflow with watershed degradation parameters. The contradiction is between 1970-1981 when comparing baseflow variation with watershed degradation indicators. During that period baseflow was increasing while watershed storage was decreasing at the same time when comparing variation of baseflow with watershed degradation factor the results shows that within that period watershed was improving and that is why baseflow has increased.

Therefore, to remove doubt on whether there was watershed improvement between 1970 and 1981 which was followed by an increase in baseflow, the effect of precipitation was removed by developing baseflow models in each watershed degradation scenario (Table 4.6).

Table 4.6 **Results of regressing monthly base flow (BF) of given probability of exceedance on monthly precipitation (P) of same probability as base flow for four Mswiswi watershed degradation scenarios**

Watershed degradation Scenario	Regression Equations	r^2	Std. Err. BF. Est.
1960-65	$BF=1.624P^{0.458}$	96	1.5
1965-75	$BF=1.137P^{0.618}$	96	6.0
1975-86	$BF=1.365P^{0.553}$	97	2.6
1986-92	$BF=0.89P^{0.692}$	94	4.4

Where in Table 4.6, BF is monthly base of a certain probability, P is monthly precipitation of a certain probability.

As for runoff, the established models are not predictive but are indicative, since their derivation has been based on probabilistic approach. Correlation coefficients squared range from 94% for 1986-92 scenario to 96% for 1960-65 scenario. These coefficients are all relatively high and therefore, the derived monthly baseflow - precipitation - watershed loss factor relations are good representation of the data.

The different equations obtained show that watershed characteristics were differing from one degradation scenario to another. The cause of this difference is watershed

degradation and climatic changes. The general equation expressing the baseflow-precipitation relationship was obtained from Table 4.6 and is given by :

$$BF = nP^{m} \quad (26)$$

Where, BF - monthly baseflow of given probability of exceedance,

P - monthly precipitation of given probability,

n,m - watershed coefficients accounting for watershed characteristic affecting baseflow.

Watershed coefficients (n,m) for baseflow in the four watershed degradation scenarios were, (1.624,0.458), (1.137,0.618), (1.365,0.553) and (0.89,0.692) in 1960-65, 1965-75, 1975-86 and 1986-92, respectively (Table 4.6). The result of regression analysis of watershed parameters for baseflow yielded the following equations:

$$n = e^{-0.043t}(1.624Cos17.3t + eSin17.3t) \quad (27)$$

$$m = 0.493e^{0.012t} \quad (28)$$

In equation (27) the absolute values are taken for n.

The obtained general baseflow-precipitation model is therefore expressed by:

$$BF=e^{-0.043t}(1.624Cos17.3t+eSin17.3t)P^{0.493e^{0.012t}} \quad (29)$$

Where, BF - monthly baseflow, mm,

P - monthly precipitation, mm,

t - time in years.

Before applying the baseflow model for the evaluation of the effect of watershed degradation, it was calibrated using April month data. The input data to this model were monthly total precipitation of each year of record. Comparison of observed and modeled baseflow show that data are in good agreement (Fig. 4.20). There was no significant difference at 95 % confidence level between the means of observed and simulated baseflow as $t = -0.80 < t^{46}_{0.025} = 2.02$

Fig 4.20 shows that baseflow was fluctuating between maximum and minimum with certain recurring interval. It is difficult from Fig 4.20 to see clearly how watershed degradation was affecting baseflow since the model incorporates both degradation factors and climatic factors. To assess the effect of watershed degradation separately, the baseflow model was run on equal rainfall events in each year as already explained for the case of runoff. The plot of baseflow simulated by the model against time is presented in Fig 4.21.

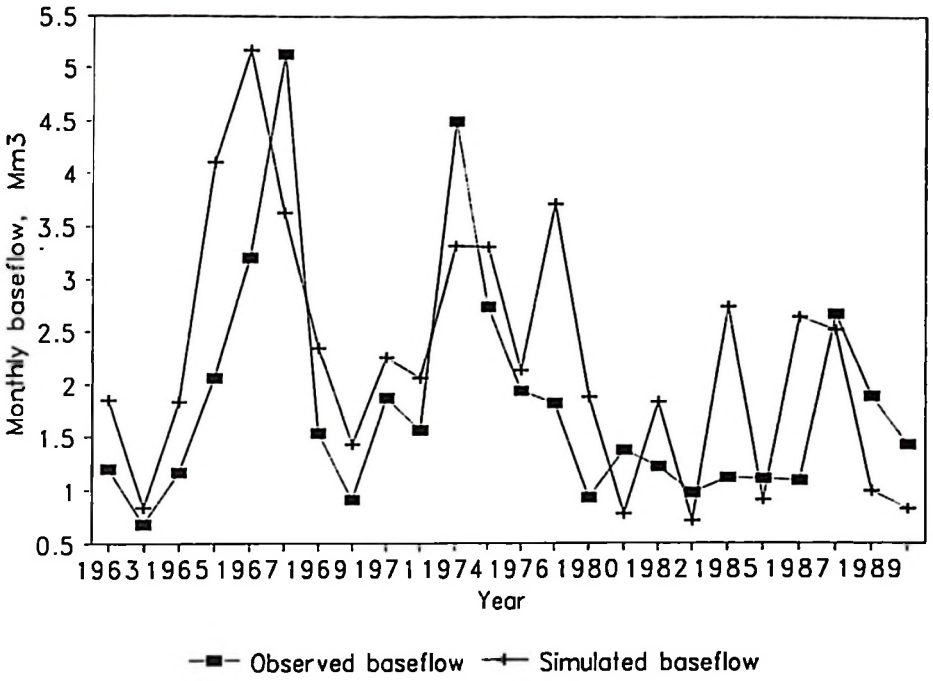

Fig 4.20 Comparison of observed and modelled April month baseflow for the period 1963-1989

The figure 4.21 shows that for similar rainfall, the watershed was responding differently. Since rainfall is constant, the only varying factor is watershed characteristics which are affected by watershed degradation. However, the way watershed degradation causes cyclic trends in baseflow is beyond the scope of this study. It can be deduced from Fig 4.21 that the same rainfall was producing maximum and minimum base flows of recurring intervals of 10 years, although their magnitude were different. For example, if 100mm rainfall had occurred in 1963 it would have produced maximum baseflow of 15.72mm. However, if it were to reoccur after 10 years, it would have produced maximum baseflow of 10.73mm in

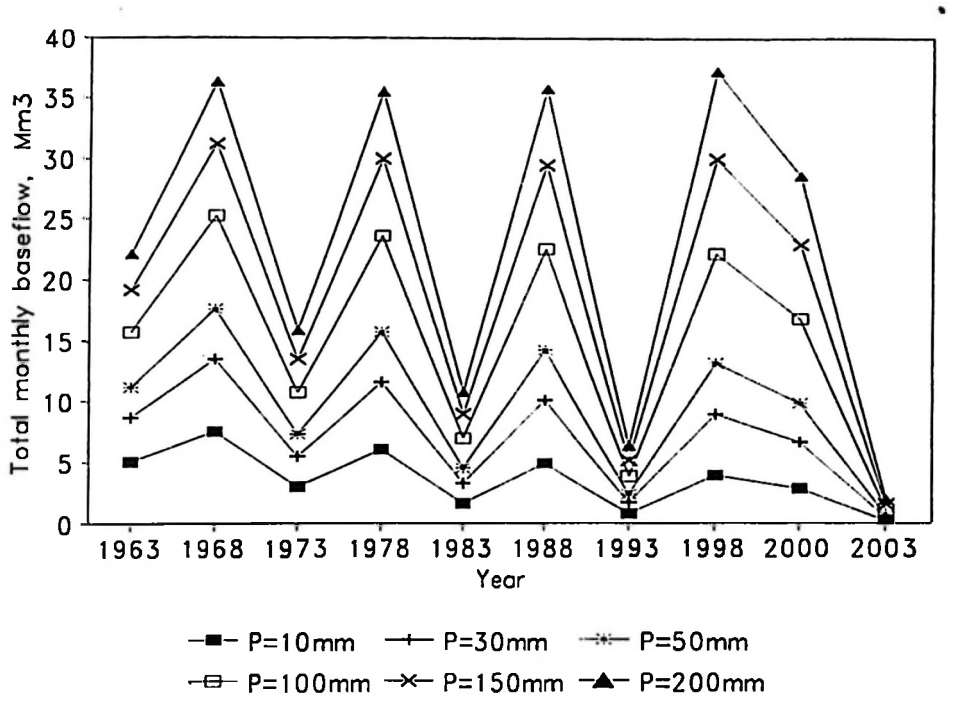

Fig 4.21 Simulated baseflow response of Mswiswi watershed to equal rainfall events

1973. It has been a custom in designing of water structures to assume that the magnitude of streamflow having the same recurring interval is constant. This can only be true when watershed characteristics are constant, i.e when there is no watershed degradation.

Fig 4.22 and 4.23 show the decreasing trend of maximum and minimum baseflow having the recurring interval of 10 Years for equal rainfall events. Fig 4.22 and 4.23 have been extracted from Fig 4.21 in order to show the decreasing trend of maximum and minimum baseflow for equal rainfall events.

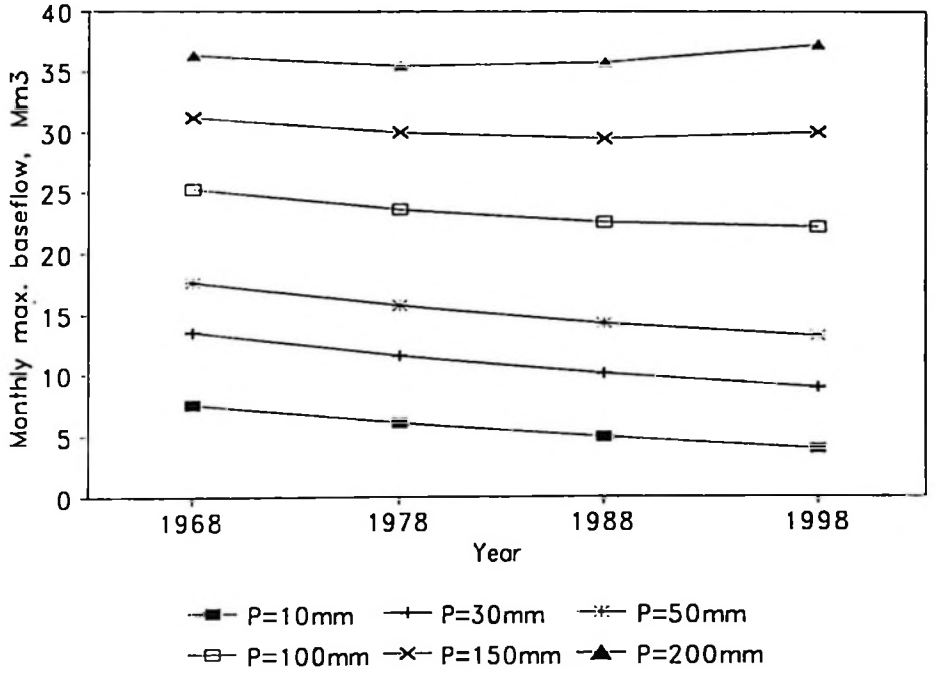

Fig 4.22 Simulated trend of maximum baseflow for equal rainfall events

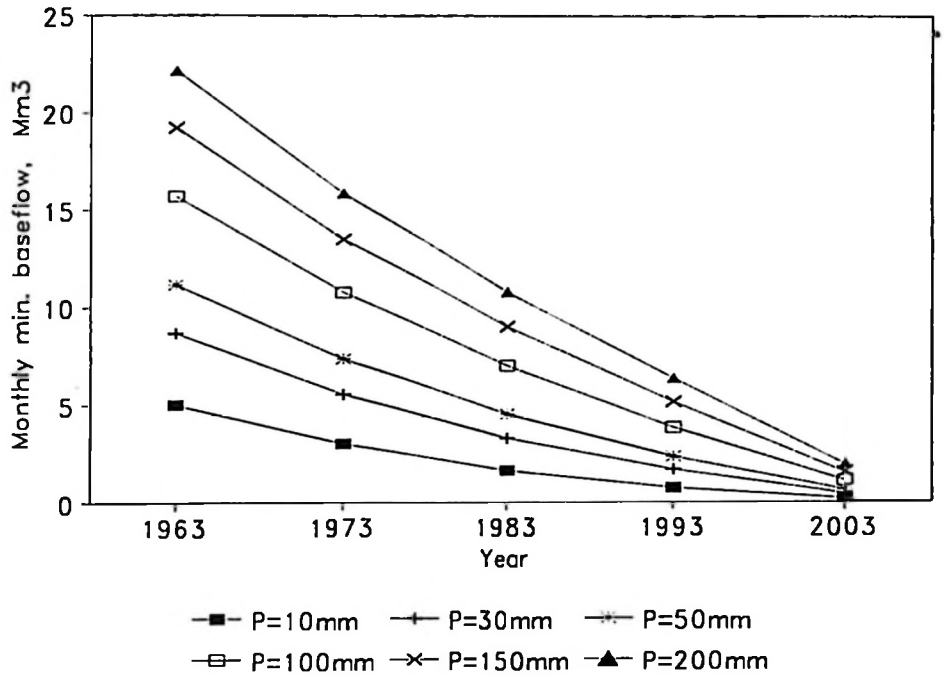

Fig 4.23 Simulated trend of minimum baseflow for equal rainfall events

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are drawn from this study :

1. Calibration of watershed upon itself by separation of the period into degradation scenarios and making comparison of the distribution of data in each scenario is a useful approach in understanding the effects of watershed degradation on streamflow characteristics. This approach replaces the common method adapted in most of researches of treating the catchment by either removing totally or partially the vegetation cover by cutting the trees or by comparing two catchments having different vegetation cover or degradation levels. The method used in this study is useful when there is no other catchment to make comparison with because of inadequate data.

2. Mswiswi watershed is degrading as shown by two evidences provided by this study. Forest loss occurs at a rate of 1.05, 0.32 and 4.97 ha/year for mixed forest, forest reserve and low dense miombo woodland, respectively. Evidence of watershed soil loss has been indicated by expansion of gullies at a rate of 4.93 ha/year.

3. Watershed parameters such as watershed storage, watershed curve number and watershed loss factor are good indicators of watershed degradation. Runoff was increasing as watershed storage and watershed loss factor were decreasing. On contrary, runoff was increasing with watershed curve number Since variation of watershed storage, curve number and loss factor is related to variation in vegetation cover, it can be concluded that runoff increases with watershed forest loss. The trend whereby runoff was increasing with decreasing precipitation was evidence that the increase in runoff with time, was due to the decreasing trend in vegetation cover.

4. The increase in runoff with time imposes a risk to water-structures to be built across river Mswiswi. Generally design discharge for water-structures is taken at 10 % probability for safety purposes on assumption that the magnitude of runoff of 10 % probability is constant. However, this study shows that runoff of 10% probability of exceedance increases with time as the watershed degrades. Thus, for example, there was runoff increase of 10 % probability of exceedance by 6.79 m^3/s from 1963 to 1989. This means that structures built in 1963 were likely to be swept by floods in 1989. This may be the reason for the collapse of several structures built by Ministry of Water between 1960 and 1970 across the rivers in the Usangu Plains.

5. Watershed degradation is causing baseflow variability. This has been shown by the correspondence between cyclic trends of watershed degradation factor and baseflow. Baseflow decreases and increases with watershed degradation factor. Decrease of baseflow with time leads to less water available for withdrawal at succeeding dates, while variability of baseflow decreases the length of time during which water can be withdrawn.

6. Streamflow in Mswiswi watershed is affected both by watershed degradation and climatic factors. The combined effect makes it difficult to establish the effect of watershed degradation on both measured and modeled streamflow data. The developed runoff and baseflow models are useful in evaluating the effect of watershed degradation on streamflow.

These models enabled to assessment of the effect of watershed degradation by eliminating the effect of precipitation on streamflow. This is achieved by keeping the latter constant for all periods of watershed degradation. With equal rainfall events runoff increases with watershed degradation.

There is cyclic trend of variability of baseflow for equal rainfall event with maximum and minimum baseflow decreasing as the watershed degrades. The recurrence interval of maximum and minimum baseflow is 10 years.

7. Existence of period of water deficit or excess in Mswiswi watershed was due to the combined effect of climatic changes and watershed degradation processes on streamflow and depended on which process was dominating.

5.2 Recommendation

1. Differences of watershed coefficients for runoff, (a and b) and baseflow, (n and m) between watershed degradation scenarios indicated that watershed characteristics were changing with watershed degradation. Further studies will be necessary in order to establish which of the watershed characteristics influence the variability of watershed coefficients for runoff and baseflow. Also more research is required in order to identify the cause of cyclic trends in baseflow for equal rainfall event as watershed degrades.

2. This study increases knowledge of the potential problems posed by watershed degradation to basin planners and decision makers, so that in future they can consider incorporating potential impacts of watershed degradation in long range planning.

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7. APPENDICES

APPENDIX A: RAINFALL CHARACTERISTICS

Table A_1: Monthly total Precipitation (mm) of selected Probability of exceedance for difference watershed degradation scenarios

Probab.of exceedance	Watershed degradation scenario			
%	1960-65	1965-75	1975-86	1986-92
0.1	509.1	508.02	428.17	369.32
0.5	505.5	500.1	420.83	366.6
1	501	490.1	411.65	363.2
2.5	467.48	455.25	367.98	352.99
5	444.98	410.5	352.64	315.99
10	417	270.83	236.69	193.33
15	386.67	351	305.96	255.98
20	371.68	321.48	274.79	228.03
25	326	287.33	258.67	204.67
30	305	254.32	221	178.23
35	275.02	235.39	187.98	160.98
40	230	203.96	155.99	146
45	197.48	172.23	138.67	134.67
50	174.99	155.01	125	123.33
55	145	130.77	113.5	112
60	130	108.4	102	103
65	85.48	89.13	90.51	94.5
70	67.5	76.77	75.34	84.67
75	56.25	46.44	57.99	73.33
80	43.33	32.29	45.66	57.99
85	29.28	25.63	38	45.5
90	22.85	20.42	30.34	37
95	16.43	15.21	22.22	27.01
100	10	10	10	10

Table A_2: Monthly Rainfall Totals at Irambo raingauge station

Year	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sept	Oct	Nov	Dec
1942	-9.9	-9.9	-9.9	247.7	11.9	14.0	.0	13.2	.0	75.7	73.2	183.9
1943	131.8	214.4	200.2	176.5	79.2	.0	.0	.0	.0	.0	9.7	78.2
1944	327.7	154.4	179.3	235.0	40.6	.0	.0	.0	12.7	55.4	208.8	434.6
1945	355.9	245.4	204.2	458.7	117.1	4.3	.0	.0	.0	14.7	137.2	260.1
1946	197.1	192.8	126.0	274.6	132.6	.0	.0	.0	.0	25.4	157.0	315.2
1947	213.1	335.0	191.5	443.0	94.2	2.3	.0	.0	.0	15.2	45.2	215.9
1948	258.6	138.2	314.5	345.9	6.3	.0	.0	.0	2.8	27.4	80.0	81.0
1949	206.5	248.2	151.6	192.0	41.1	.0	.0	.0	.0	14.2	8.4	183.6
1950	422.7	244.3	333.5	285.0	47.2	.0	4.3	.0	.0	43.2	114.6	149.9
1951	222.0	364.2	227.8	312.7	12.4	.0	.0	5.8	15.7	7.6	169.7	321.8
1952	218.7	305.1	215.9	353.6	95.5	.0	.5	.0	20.1	17.8	122.9	33.0
1953	306.3	77.7	171.2	249.4	52.1	.0	.0	.0	9.9	1.3	41.4	294.9
1954	232.4	200.4	208.0	156.7	44.7	.0	.0	3.3	18.3	2.5	18.5	178.8
1955	142.5	205.5	352.8	225.8	95.3	3.6	.0	.0	.0	9.1	17.3	256.0
1956	279.7	289.3	400.8	383.0	96.8	6.3	.0	.0	.0	6.9	47.0	166.1
1957	352.3	202.4	310.4	403.1	61.2	.0	.0	.0	.0	7.6	37.1	261.9
1958	190.8	264.7	465.8	113.3	22.9	.0	.0	.0	12.7	7.6	85.1	-9.9
1959	326.6	215.4	333.5	176.8	26.7	3.0	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9
1960	195.1	178.6	421.4	360.9	41.1	5.1	3.8	.0	24.9	.0	8.4	130.3
1961	130.3	319.0	224.3	397.3	.0	-9.9	.0	.0	7.1	79.2	133.9	304.0
1962	304.3	285.5	447.8	304.5	-9.9	-9.9	-9.9	-9.9	-9.9	55.4	56.9	252.7
1963	493.3	318.4	364.5	185.1	18.3	.0	.0	.0	.0	31.0	283.9	174.5
1964	326.0	153.2	206.5	18.21	53.8	.0	.0	.0	.0	.0	32.4	99.4
1965	97.2	268.9	226.5	61.1	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	7.7	379.7
1966	200.9	234.2	680.7	258.4	22.1	.0	.0	.0	7.8	121.9	127.8	252.5
1967	152.1	391.8	324.1	415.3	83.9	10.2	.6	.3	35.9	28.6	204.7	374.4
1968	164.1	260.4	351.4	260.4	67.2	15.1	.0	.0	5.4	17.1	29.6	218.9
1969	243.4	307.5	150.0	177.1	53.4	.0	.0	.0	.0	8.0	47.6	174.0
1970	283.6	179.9	330.4	157.3	11.5	2.0	1.0	.0	.0	13.5	107.2	451.4
1971	220.2	286.3	187.0	261.1	21.7	.0	.0	.0	18.0	40.5	82.5	263.5
1972	143.1	291.1	458.9	221.1	94.5	.0	.0	12.2	.0	113.0	61.8	251.9
1973	276.4	229.5	419.7	317.1	72.6	.0	.0	.0	5.0	87.3	70.1	126.0
1974	339.0	131.0	26.7	408.2	143.5	.0	4.0	.0	4.0	38.0	69.0	194.0
1975	260.0	111.0	360.0	258.5	61.6	.0	.0	.0	.0	102.7	3.8	144.1
1976	237.6	209.0	244.1	97.6	2.0	-9.9	-9.9	-9.9	-9.9	27.5	21.9	93.8
1977	263.6	156.0	107.4	244.2	74.3	.0	.0	.0	.0	35.3	96.4	265.5
1980	311.5	72.4	340.7	200.9	102.8	.0	.0	.0	11.2	6.8	112.9	235.6
1981	141.9	249.1	293.3	135.9	48.9	.0	.0	.0	22.3	26.2	56.6	214.0
1982	60.8	113.3	153.8	210.4	99.3	.0	1.0	.0	.0	81.2	177.4	291.0
1983	204.9	202.4	316.6	128.0	46.6	.0	.0	.0	5.0	.0	35.4	112.4
1984	341.2	63.7	139.8	56.0	3.2	.0	.0	.0	.0	.0	.0	153.8
1985	35.0	125.7	166.5	229.6	22.6	.0	.0	-9.9	-9.9	-9.9	234.4	228.8
1986	241.9	92.2	211.2	31.9	68.9	-9.9	-9.9	-9.9	-9.9	-9.9	22.4	359.5
1987	317.7	198.3	195.0	149.9	-9.9	-9.9	-9.9	-9.9	-9.9	-9.9	20.1	85.2
1988	185.4	100.4	163.3	146.0	83.0	-9.9	-9.9	-9.9	-9.9	92.8	108.9	175.1
1989	254.8	102.1	65.9	58.5	-9.9	-9.9	-9.9	-9.9	-9.9	0.5	77.9	131.4
1990	91.7	226.2	128.4	54.6	0.0	0.0	0.0	0.0	0.1	34.3	65.7	131.8

* -9.9 means there was no record

APPENDIX B: WATERSHED LOSS FACTOR

Table B_1 : Comparison of monthly watershed Loss Factor (WLF) in four watershed degradation scenarios

Probab. of Exceedance	Watershed degradation scenario			
%	1960-65	1965-75	1975-86	1986-92
0.1	1.05	1.05	1.05	1.05
0.5	1.05	1.05	1.04	1.04
1	1.05	1.05	1.05	1.05
2.5	1.04	1.04	1.04	1.04
5	1.04	1.04	1.02	1.02
10	1.03	1.02	1.01	1
15	1.02	1.01	0.99	0.97
20	1.01	0.99	0.98	0.95
25	1	0.98	0.97	0.93
30	0.99	0.97	0.95	0.91
35	0.98	0.95	0.93	0.9
40	0.96	0.93	0.91	0.88
45	0.95	0.89	0.88	0.87
50	0.94	0.86	0.86	0.85
55	0.92	0.82	0.82	0.78
60	0.9	0.77	0.78	0.72
65	0.88	0.72	0.73	0.65
70	0.85	0.66	0.66	0.63
75	0.81	0.61	0.58	0.6
80	0.77	0.57	0.53	0.57
85	0.71	0.51	0.48	0.55
90	0.53	0.39	0.24	0.48
95	0.145	0.19	0.15	0.22
100	0.05	0.05		0.15

Table B_2 : Mswiswi watershed - Monthly watershed loss factor

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1960	0.77	0.7	0.95	0.94	NR	*	*	*	*	*	0.49	0.97
1961	0.95	0.9	0.63	0.79	0.17	*	*	*	*	*	0.93	0.83
1962	0.87	0.77	0.97	0.95	0.93	*	*	*	*	*	0.93	0.97
1963	0.94	0.9	0.88	0.88	NR	*	*	*	*	*	0.98	0.93
1964	0.85	0.64	0.77	0.07	NR	0	*	*	*	*	0.97	0.97
1965	0.96	0.94	0.82	NR	NR	*	*	*	*	*	0.84	1
1966	0.84	0.77	0.66	0.17	NR	*	*	*	*	*	0.94	0.97
1967	0.9	0.94	0.91	0.91	0.47	*	*	*	*	*	0.91	0.73
1968	0.82	0.85	0.86	0.77	NR	*	*	*	*	*	0.76	0.96
1969	0.93	0.7	0.39	0.54	0.09	0.57	*	*	*	*	*	0.99
1970	0.97	0.61	0.28	0.05	NR	*	*	*	*	*	0.7	0.99
1971	0.74	0.55	0.53	0.6	NR	*	*	*	*	*	1	0.99
1972	NR	0.54	0.53	0.32	0.42	*	*	*	*	*	0.97	0.99
1974	0.96	0.69	NR	0.22	*	*	*	*	*	*	0.84	0.93
1975	0.82	0.68	0.72	0.47	*	*	*	*	*	*	0.91	0.92
1976	0.91	0.82	0.58	NR	*	*	*	*	*	*	0.49	0.88
1977	0.92	0.75	0.73	0.75	*	*	*	*	*	*	0.96	
1978	0.92	0.75	0.73	0.75	*	*	*	*	*	*	0.95	0.66
1980	0.96	0.86	0.97	0.7	0.77	*	*	*	*	*	0.94	0.96
1981	0.87	0.69	0.83	0.45	0.63	*	*	*	*	*	0.89	0.97
1982	0.85	0.88	0.92	0.86	0.32	*	*	*	*	*	0.96	0.96
1984	0.97	0.74	0.5	NR	*	*	*	*	*	*	*	0.92
1985	0.18	0.17	0.44	0.47	*	*	*	*	*	*	0.95	0.94
1986	0.92	0.19	0.52	NR	0.58	*	*	*	*	*	0.54	0.86
1987	0.93	0.79	0.77	0.87	*	*	*	*	*	*	0.62	0.91
1988	0.86	0.47	0.52	NR	0.54	*	*	*	*	*	0.9	0.87
1989	0.89	0.18	NR	NR	*	*	*	*	*	*	0.88	0.91
1990	0.66	0.92	0.48		*	*	*	*	*	*	0.83	0.87

NR- No data record
* - Watershed loss factor approaches very big negative values.

APPENDIX C : WATERSHED DEGRADATION FACTOR

Monthly watershed degradation factor (WDF) has been computed using equation (3.7). In equation (3.7), peak runoff, q_p is given by:

$$q_p=3.79A^{0.7}(CS)^{0.16}(RO/25.4)^{0.903A^{0.017}}(LW)^{-0.19} \quad (30)$$

Where, q_p - peak flow rate in m^3/s,
A - the drainage area in km^2, =87.05
CS - channel slope in m/km, =35
RO - runoff volume in mm,
LW - watershed length-width ration = 6.48

Soil erodibility in equation (3.7) is given by equation:

$$K=2.8*10^{-7}M^{1.14}(12-a)+4.3*10^{-3}(b-2)+3.3*10^{-3}(c-3) \quad (31)$$

Where, M = particle size(% silt + % very fine sand)*(100-% % clay)
M= (30+46)*(100-24)/100= 57.76 %

Length slope (LS) in equation (3.7) is calculated from equation:

$$LS=(x/22.1)^m(0.065+0.045s+0.006s^2) \quad (32)$$

Where, x - slope length =23750 m
m = 0.5
s - slope = 6 %

Substituting the known watershed characteristic in above equations watershed degradation factor (WDF) for Mswiswi watershed is therefore expressed by equation given by:

$$WDF=220.056(RO)^{1.105} \quad (33)$$

Where, RO - runoff volume in mm

Based on the above equation monthly watershed degradation factor data were generated (Table C_2)

Table C_1 : Comparison of watershed degradation factor of selected probability of exceedance in four degradation scenarios

Probability of exceedance %	Watershed degradation scenario 1960-65	1965-75	1975-86	1986-92	Avg WDF
5	28.57	87.05	37.17	64.87	54.42
10	19.79	45.03	23.62	35.59	31.01
15	15.96	30.62	18.12	25.05	22.44
20	13.70	23.29	15.01	19.53	17.88
25	12.18	18.84	12.97	16.10	15.02
30	11.05	15.84	11.51	13.75	13.04
35	10.19	13.68	10.41	12.03	11.58
40	9.49	12.05	9.54	10.71	10.45
45	8.92	10.77	8.83	9.68	9.55
50	8.43	9.74	8.24	8.83	8.81
55	8.02	8.90	7.75	8.13	8.20
60	7.66	8.19	7.32	7.54	7.68
65	7.34	7.59	6.94	7.04	7.23
70	7.06	7.08	6.62	6.60	6.84
75	6.80	6.63	6.32	6.22	6.49
80	6.57	6.23	6.06	5.88	6.19
85	6.37	5.88	5.83	5.58	5.91
90	6.18	5.57	5.61	5.31	5.67
95	6.00	5.29	5.42	5.07	5.44

Table C_2 : Mswiswi monthly watershed degradation factor

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual average
1961	0.00	5.91	23.48	23.48	13.95	0.00	0.00	0.00	0.00	0.00	0.31	13.70	6.74
1962	8.95	16.96	0.40	0.00	9.67	1.82	0.00	0.00	0.00	0.00	0.00	0.74	3.21
1963	6.44	6.79	9.71	2.38	16.32	1.06	0.00	0.00	0.00	0.00	0.46	0.10	3.61
1964	13.20	15.82	12.87	2.48	14.82	0.71	0.00	0.00	0.00	0.00	0.00	0.02	4.99
1965	0.00	2.41	9.82	46.39	11.69	0.00	0.00	0.00	0.00	0.00	0.00	0.12	5.87
1966	8.12	13.12	81.64	72.82	12.34	0.00	0.00	0.00	0.00	0.00	0.00	0.04	15.67
1967	0.17	6.41	13.49	51.25	19.33	0.00	0.00	0.00	0.00	0.00	0.00	26.85	9.79
1968	49.85	36.66	63.00	64.43	21.14	0.00	0.00	0.00	0.00	0.00	0.00	0.23	19.61
1969	2.17	26.63	26.46	21.79	8.91	0.00	0.00	0.00	0.00	0.00	0.00	0.23	7.18
1970	0.99	21.10	88.62	51.20	10.31	0.00	0.00	0.00	0.00	0.00	0.00	7.68	14.99
1971	15.19	41.01	24.35	28.58	25.49	0.00	0.00	0.00	0.00	0.00	0.00	0.46	11.26
1972	55.77	44.68	77.87	47.93	10.83	0.00	0.00	0.00	0.00	0.00	0.00	0.23	19.78
1974	0.00	3.88	0.20	106.16	68.56	0.00	0.00	0.00	0.00	0.00	0.00	0.64	14.95
1975	8.32	3.63	24.61	37.84	20.45	0.00	0.00	0.00	0.00	0.00	0.00	0.15	7.92
1976	1.69	6.02	29.38	31.74	11.89	0.00	0.00	0.00	0.00	0.00	0.00	0.15	6.74
1977	1.82	6.25	2.84	12.83	21.48	0.00	0.00	0.00	0.00	0.00	0.00	0.20	3.79
1978	0.00	15.99	89.42	29.42	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.40
1980	0.77	0.02	0.23	16.37	3.70	0.00	0.00	0.00	0.00	0.00	0.00	0.15	1.77
1981	1.93	22.52	11.00	19.68	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.04	4.69
1982	0.00	0.55	0.02	4.48	15.70	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.80
1984	0.09	1.86	20.19	2.06	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.06	2.13
1985	5.91	34.53	28.62	39.30	8.43	0.00	0.00	0.00	0.00	0.00	0.00	0.55	9.78
1986	2.17	21.40	31.74	23.74	4.62	0.00	0.00	0.00	0.00	0.00	0.00	12.99	8.06
1987	2.17	8.55	9.39	1.93	0.46	0.00	0.00	0.00	0.00	0.00	0.09	25.90	4.04
1988	1.38	9.11	17.04	46.63	4.33	0.00	0.00	0.00	0.00	0.00	0.34	3.37	6.85
1989	2.59	22.34	37.41	76.17	4.25	0.00	0.00	0.00	0.00	0.00	0.00	0.67	11.95
1990	5.52	1.09	17.33	65.34	10.14	0.00	0.00	0.00	0.00	0.00	0.00	1.48	8.41
1991	6.48	9.83	3.09	89.17	7.73	0.00	0.00	0.00	0.00	0.00	0.00	0.02	9.69
1992	1.22	17.46	84.04	85.72	83.50	5.11	0.00	0.00	0.00	0.00	0.00	3.77	23.40

APPENDIX D : WATERSHED CURVE NUMBER

Table D_1 : Comparison of monthly curve number selected probability of exceedance in four watershed degradation scenarios

Probab. of Exceedance	Watershed Degradation Scenario			
%	1960-65	1965-75	1975-86	1986-92
2.5	101.12	101.85		
5	97.25	98.7	101.33	102.57
10	74.01	91.76	97.67	100.14
15	58.5	84.1	92	97.71
20	51	77.8	78.99	95.28
25	45.84	69.16	72.5	87.5
30	43.38	63.27	69.2	79
35	41.44	60.41	65.9	73.2
40	39.5	57.54	60.2	69.8
45	37.56	54.41	54.12	66.4
50	35.62	49.17	50	60
55	33.95	44.35	45.87	52.66
60	32.4	41.2	42.64	47
65	30.85	38.05	39.64	43.43
70	29.3	34.9	36.64	41
75	27.75	31.75	33.33	38.57
80	26.2	28.6	29.67	36.14
85	24.3	25.45	26	33.2
90	21.2	22	22.33	29.8
95	18.1	18.5	18.67	26.4
100	15	15	15	15

Table D_2 : **Mswiswi watershed monthly curve number**

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
1961	28.1	22.3	49.4	25.8	100	100	100	100	87.7	39.1	32.4	29.6
1962	25.92	35.5	11.55	14.3	100	100	100	100	100	100	47.17	20.5
1963	14.4	23.1	21.9	31.3	100	100	100	100	100	62.1	17.8	30.4
1964	26.97	59.25	42.57	95.44	96.84	100	100	100	100	100	61.06	38.9
1965	34.32	22.32	35.8	100	100	100	100	100	100	100	86.84	12.74
1966	38	38	24.6	85.3	84.8	100	100	100	100	86.7	28.4	17.6
1967	28.3	18.3	27.4	36.5	51.9	83.3	98.8	99.4	58.6	64	19.9	21.1
1968	90.3	52.2	51	72	98.3	77.1	100	100	90.4	74.8	63.2	21.3
1969	24.1	38.01	72.9	59.3	89.1	100	100	100	100	86.4	51.6	25.8
1970	19	57.8	69.9	93.7	100	96.2	98.1	100	100	79	32.2	16.4
1971	42.4	50.4	59.3	46.2	100	100	100	100	73	55.6	38.1	19
1972	100	51.5	41.7	70.5	73.1	100	100	80.6	100	31	45.1	18.9
1974	13	45.7	74.5	62.3	0.6	100	92.7	100	92.7	57.2	42.4	25.5
1975	29.8	51	30.3	53.5	99.6	100	100	100	100	33.1	93	29.5
1976	23.8	33.91	50.1	97.41	100	100	100	100	100	100	69.88	39.71
1977	21.85	44.33	49.8	36.17	96.09	100	100	100	100	100	34.51	17.94
1978	12.04	43.36	89.62	100	100	100	100	100	100	100	63.26	11.06
1980	17	43.38	14.45	47.56	54.03	100	100	100	100	100	31.03	19.69
1981	37.8	43.7	28.6	70	68.3	100	100	100	69.5	66	47.3	20.3
1982	45.5	38.4	25.9	31.5	78.8	100	98.1	100	100	38.5	23.9	18
1984	14	64	69.2	69.2	94.1	100	100	100	100	100	100	32.6
1985	93.19	89.95	69.73	61.33	100	100	100	100	100	100	17.81	21.83
1986	24.27	89.01	59.74	100	71.44	100	100	100	100	100	69.4	24.15
1987	18.76	39.06	40.72	36.15	100	100	100	100	100	100	71.65	41.34
1988	28.87	67.48	57.86	93.72	63.81	100	100	100	100	100	37.9	35.02
1989	23.77	86.15	100	100	100	100	100	100	100	100	39.47	35.09
1990	63.3	23.56	69.64	100	100	100	100	100	100	100	43.6	38.51

APPENDIX E : WATERSHED STORAGE

Table E_1 : Comparison of monthly watershed storage in four Mswiswi watershed degradation scenarios

Probability of exceedance of Monthly watershed storage	Watershed degradation scenario			
	1960-65	1965-75	1975-86	1986-92
2.5	-2.81	-4.61		
5	7.18	3.34	-3.33	-6.36
10	89.2	22.8	6.06	-0.35
15	180.19	48.02	22.09	5.95
20	244.03	72.48	67.55	12.58
25	300.1	113.26	96.34	36.28
30	331.52	147.45	113.05	67.52
35	358.93	166.46	131.43	92.99
40	389.04	187.43	167.93	109.89
45	422.25	212.83	215.33	128.53
50	459.08	262.58	254	169.33
55	494.16	318.72	299.73	228.34
60	529.95	362.5	341.68	286.43
65	569.34	413.54	386.77	330.84
70	612.89	473.79	439.23	365.51
75	661.32	546	508.08	404.54
80	715.46	634.11	602.08	448.82
85	791.27	744.03	722.92	511.06
90	944.11	900.54	883.48	598.35
95	1149.31	1118.97	1106.47	708.12

APPENDIX F : STREAMFLOW CHARACTERISTICS

Table F_1 : Monthly and annual water yield (Mm3) from Mswiswi watershed

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
1960	3.89	4.63	1.89	1.78	4.73	2.33	1.42	0.92	0.65	0.46	0.37	0.32	23.46
1961	0.59	2.7	7.29	7.26	5.72	2.34	1.49	1.09	0.7	0.68	0.8	4.46	35.14
1962	3.48	5.52	1.32	0.99	3.9	1.83	1.25	0.67	0.43	0.42	0.33	0.59	20.73
1963	2.69	2.9	3.76	1.96	5.62	1.76	1.17	0.8	0.44	0.41	0.57	1.04	23.12
1964	4.16	4.81	4.12	1.47	4.67	1.12	0.88	0.37	0.22	0.08	0.08	0.16	22.18
1965	0.31	1.36	3.6	12.12	4.63	1.16	0.5	0.27	0.18	0.13	0.11	0.16	24.46
1966	2.89	4.61	19.98	18.66	5.88	2.8	1.81	1.1	0.79	0.66	0.65	0.67	60.49
1967	1.36	3.76	6.17	15.28	8.84	4.47	3.19	2.58	2.24	2.01	1.64	8.73	60.27
1968	14.29	12.3	18.82	19.99	11.42	3.86	2.25	1.75	1.32	0.74	0.61	0.7	88
1969	1.53	7.95	7.95	7.11	4.25	1.7	1.02	0.7	0.48	0.22	0.21	0.3	32.51
1970	0.79	6.02	20.58	12.98	3.89	1.22	0.83	0.74	0.42	0.3	0.27	2.76	50.8
1971	4.93	11.24	7.71	8.99	6.6	1.76	1.21	0.86	0.63	0.31	0.28	0.71	45.23
1972	13.83	11.72	18.95	12.54	4.78	1.53	0.72	0.48	0.27	0.21	0.16	0.25	65.44
1974	1.23	3.59	3.45	27.85	21.31	5.22	3.03	1.76	1.23	0.99	0.98	1.23	71.77
1975	4.02	1.91	8.61	11.92	8.34	2.46	1.69	1.59	1.15	1.14	1	1.07	44.9
1976	1.84	2.45	9.02	9.77	5.38	2.13	1.67	1.35	1.17	1.09	0.98	1.04	37.85
1977	1.91	3.29	2.54	5.28	7.5	1.42	0.98	0.87	0.81	0.81	0.79	0.87	27.07
1978	1.19	3.8	22.99	9.7	2.4	1.17	0.86	0.85	0.81	0.81	0.81	0.8	46.45
1980	1.09	0.87	0.98	5.23	2.09	0.75	0.68	0.64	0.59	0.6	0.6	0.83	14.95
1981	1.56	6.85	4.28	6.46	1.58	0.74	0.69	0.56	0.58	0.59	0.53	0.55	24.97
1982	0.59	1.15	1.1	2.56	5.5	0.95	0.75	0.66	0.58	0.59	0.62	0.9	15.85
1984	0.79	1.43	6.1	1.64	1.05	0.8	0.7	0.62	0.48	0.48	0.58	1.05	15.48
1985	0.69	9.35	8.14	10.62	3.58	0.84	1.12	1.05	0.92	0.94	0.94	1	39.19
1986	1.7	6.52	8.9	7.13	2.51	0.84	1.06	0.99	0.91	0.91	0.9	4.39	36.76
1987	1.76	73.12	6.86	13.76	3.29	1.02	0.97	0.89	0.8	0.78	0.97	1.99	106.21
1988	2.19	7.28	10.87	19.19	2.9	0.97	1.08	1	0.89	0.89	0.84	1.08	49.18
1989	2.69	1.57	5.85	16.5	4.34	1.38	0.77	1.09	1.02	0.99	11.01	1.5	38.71

Table F_2 : Annual peak, minimum and mean stream flow (m^3/s) from Mswiswi watershed

Year	Annual peak	Annual min.	Annual mean
1960	7.06	0.15	0.73
1961	4.17	0.13	1.11
1962	17.12	0.08	0.66
1963	5.8	0.11	0.95
1964	4.37	0.01	0.7
1965	10.11	0.01	0.78
1966	15.29	0.25	1.87
1967	12.41	0.23	1.91
1968	25.32	0.03	2.79
1969	5.59	0.02	1.05
1970	16.88	0.09	1.62
1971	10.46	0.05	1.2
1972	42.98	0.01	2.09
1974	45.21	0.02	2.28
1975	9.74	0.32	1.42
1976	8.3	0.33	1.2
1977	9.93	0.3	0.86
1978	14.99	0.3	1.47
1980	5.78	0.19	0.48
1981	5.53	0.19	0.81
1982	5.17	0.2	0.51
1984	5.82	0.18	0.49
1985	42.87	0.21	1.26
1986	46.81	0.21	1.6
1987	5.38	0.26	0.54
1988	9.44	0.21	3.48
1989	24.41	0.21	1.58
1990	22.08	0.21	1.23
1991	28.09	0.19	1.71
1992	19.81	0.32	3.26

Table F_3 : Response of Mswiswi Watershed to Precipitation

Year	Annual Ppt Total(mm)	Annual Baseflow Total(mm)	Annual Runoff (mm)	Annual Watershed Yield(mm)
1961	1595.1	165	238.5	403.5
1962	1707.1	119	121.8	240.8
1963	1869	121.9	143.7	265.6
1964	889.3	67.95	185.6	253.55
1965	1041.1	87.7	203	290.7
1966	1906.3	187.6	507.3	694.9
1967	1866.4	355.4	336.9	692.3
1968	1389.6	372.4	639.1	1011.5
1969	1161	130.6	256.7	387.3
1970	1537.8	93.6	489.9	583.5
1971	1380	161.4	389.4	550.8
1972	1647.6	122	640.7	762.7
1974	1357.4	376	465.8	841.8
1975	1201.7	263.5	277.5	541
1976	933.5	209	237.8	446.8
1977	1242.3	178.29	142.3	320.6
1978	1310.7	197	369.1	566.1
1980	1394.8	107.4	66.3	173.7
1981	1188.2	119.2	170.6	289.8
1982	1187.2	123.3	68.8	210.1
1984	757.7	100.6	80	180.6
1985	1042.6	142.4	337.2	479.6
1986	1028	140.3	285.8	426.1
1987	966.2	127.27	74.9	202.2
1988	1054.9	202.2	227.8	430
1989	691.1	174.38	395.3	569.

Table F_4 : Monthly and annual baseflow (Mm^3) from Mswiswi watershed

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1961	0.59	0.99	1.33	1.67	2	2.34	1.49	1.09	0.7	0.68	0.68	0.8	14.36
1962	0.99	1.08	1.17	1.22	1.23	1.24	1.25	0.67	0.43	0.42	0.33	0.33	10.36
1963	0.84	0.96	1.08	1.21	1.33	1.4	1.17	0.8	0.44	0.41	0.4	0.57	10.61
1964	0.62	0.64	0.66	0.69	0.74	0.87	0.88	0.37	0.22	0.08	0.08	0.08	5.93
1965	0.31	0.6	0.89	1.17	1.46	1.75	0.5	0.27	0.18	0.13	0.11	0.11	7.48
1966	0.6	1.09	1.57	2.06	2.55	2.8	1.81	1.1	0.79	0.66	0.65	0.65	16.33
1967	1.29	1.92	2.56	3.2	3.84	4.47	3.19	2.58	2.24	2.01	1.64	2	30.94
1968	2.51	3.38	4.26	5.13	6	3.86	2.25	1.75	1.32	0.74	0.61	0.61	32.42
1969	0.84	1.07	1.31	1.54	1.77	2	1.02	0.7	0.48	0.22	0.21	0.21	11.37
1970	0.45	0.61	0.75	0.91	1.06	1.22	0.83	0.74	0.42	0.3	0.27	0.59	8.15
1971	0.91	1.23	1.55	1.87	2.18	2.5	1.21	0.86	0.63	0.31	0.28	0.54	14.05
1972	0.79	1.05	1.31	1.57	1.82	2.08	0.72	0.48	0.27	0.21	0.16	0.16	10.62
1974	1.24	2.32	3.41	4.5	5.59	6.67	3.03	1.78	1.23	0.99	0.98	1	32.73
1975	1.69	2.04	2.39	2.74	3.08	3.43	1.69	1.59	1.15	1.14	1	1	22.94
1976	1.29	1.51	1.72	1.94	2.16	2.34	1.67	1.35	1.17	1.09	0.98	0.98	18.2
1977	1.32	1.49	1.66	1.83	2	2.17	0.98	0.87	0.81	0.81	0.79	0.79	15.52
1978	1.58	2.29	3	2.39	1.78	1.17	0.86	0.85	0.81	0.81	0.81	0.8	17.15
1980	0.82	0.86	0.89	0.93	0.97	1	0.68	0.64	0.59	0.6	0.6	0.77	9.35
1981	0.94	1.11	1.28	1.38	1.19	1	0.69	0.56	0.58	0.59	0.53	0.53	10.38
1982	0.81	0.95	1.09	1.23	1.36	1.5	0.75	0.66	0.58	0.59	0.59	0.62	10.73
1984	0.75	0.83	0.9	0.98	1.05	0.8	0.7	0.62	0.48	0.48	0.48	0.69	8.76
1985	0.79	0.9	1.01	1.12	1.22	1.33	1.12	1.05	0.92	0.94	0.94	0.97	12.11
1986	1.01	1.04	1.07	1.11	1.14	1.17	1.06	0.99	0.91	0.91	0.9	0.9	6.53
1987	1.12	1.23	1.22	1.09	0.97	0.84	0.77	0.73	0.67	0.69	0.66	0.66	10.81
1988	1.87	2.13	2.4	2.67	2	1.33	0.93	0.89	0.8	0.78	0.84	0.96	17.59
1989	1.38	1.58	1.78	1.89	1.63	1.38	1.08	1	0.89	0.89	0.84	0.84	15.17
1990	1.08	1.2	1.32	1.44	1 55	1.67	0.77	1.09	1.02	0.99	1.01	1.01	13.15

Table F_5 : Comparison of monthly baseflow in four watershed degradation scenario

Probability of exceedance %	Watershed degradation Scenario			
	1960-65	1965-75	1975-86	1986-92
0.1	34.87	74.28	44.77	64.75
0.5	34.33	71.4	43.83	63.77
1	33.67	67.87	42.67	62.55
2.5	31.66	62.34	39.17	58.87
5	28.33	56.34	34.45	52.75
10	24.44	44.66	30.56	42
15	23.33	38.67	26.67	34.68
20	22.22	33.93	24.5	32.46
25	21.11	31.16	23.62	30.23
30	20	28.39	22.75	28
35	18.89	25.61	21.87	25.77
40	17.78	23.83	21	24.33
45	16.67	22.33	20.13	23.31
50	15.56	20.83	19.25	22.29
55	14.47	19.33	18.38	21.27
60	13.42	17.83	17.5	20.25
65	12.37	16.33	16.63	19.23
70	11.32	14.82	15.75	18.21
75	10.26	13.18	14.72	17.19
80	9.21	11.52	12.78	16.17
85	8.16	9.91	10.83	15.14
90	7.11	8.27	8.89	12
95	6.05	6.64	6.94	8.5
100	5	5	5	5

Table F_6 : Monthly and annual runoff (Mm3) from Mswiswi watershed

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1961	0	1.71	5.96	5.59	3.72	0	0	0	0	0	0.12	3.66	20.76
1962	2.49	4.44	0.15	0	2.67	0.59	0	0	0	0	0	0.26	10.6
1963	1.85	1.94	2.68	5.68	4.29	0.36	0	0	0	0	0.17	0.47	12.51
1964	3.54	4.17	3.46	0.78	3.93	0.25	0	0	0	0	0	0.08	16.21
1965	0	0.76	2.71	2.74	3.17	0	0	0	0	0	0	0.05	17.73
1966	2.28	3.52	18.41	7.43	3.33	0	0	0	0	0	0	0.02	44.16
1967	0.07	1.84	3.61	12.08	5	0	0	0	0	0	0	6.73	29.33
1968	11.78	8.92	14.56	7.69	5.42	0	0	0	0	0	0	0.09	55.63
1969	0.69	6.68	6.64	5.57	2.48	0	0	0	0	0	0	0.09	22.35
1970	0.34	5.41	19.83	5.41	2.83	0	0	0	0	0	0	2.17	242.65
1971	4.02	10.01	6.16	7.12	6.42	0	0	0	0	0	0	0.17	33.9
1972	13.04	10.67	17.64	11.37	2.96	0	0	0	0	0	0	0.09	55.77
1974	0	1.17	0.08	13.37	15.72	0	0	0	0	0	0	0.23	40.55
1975	2.33	1.1	6.22	9.18	5.26	0	0	0	0	0	0	0.07	24.16
1976	0.55	1.74	7.3	5.30	3.22	0	0	0	0	0	0	0.06	20.7
1977	0.59	1.8	0.88	8.58	5.5	0	0	0	0	0	0	0.08	12.3
1978	0	4.21	19.99	4.30	0.62	0	0	0	0	0	0	0	32.13
1980	0.27	0.01	0.09	4.3	1.12	0	0	0	0	0	0	0.06	5.85
1981	0.62	5.74	3	5.08	0.39	0	0	0	0	0	0	0.02	14.85
1982	0	0.2	0.01	8.31	4.14	0	0	0	0	0	0	0.28	5.99
1984	0.04	0.6	5.2	0.66	0	0	0	0	0	0	0.1	0.36	6.96
1985	1.71	8.45	7.13	9.5	2.36	0	0	0	0	0	0	0.2	29.35
1986	0.69	5.48	7.83	1.20	1.37	0	0	0	0	0	0	3.488	21.3776
1987	0.69	2.39	2.6	6.66	0.17	0	0	0	0	0	0.04	6.514	6.51
1988	0.46	2.53	4.46	6.64	1.29	0	0	0	0	0	0.13	1.029	19.8186
1989	0.81	5.697	9.085	3.15	1.27	0	0	0	0	0	0	0.24	34.39
1990	1.609	0.37	4.527	2.89	2.79	0	0	0	0	0	0	0.49	24.8359

Table F_7 : Comparison of monthly runoff in four watershed degradation scenarios

Probability of exceedance %	Watershed degradation scenario			
	1960-65	1965-75	1975-86	1986-92
0.1	191.93	213.41	244.59	267.99
0.5	187.44	208.56	241.79	265.55
1	183.17	204.67	238.46	263.03
2.5	171.26	190.7	221.25	243.47
5	120.98	143.23	178.21	203.65
10	84.49	114.8	157.73	188.95
15	82.74	98.74	123.87	142.15
20	46.23	62.13	87.13	105.31
25	44.72	56.2	74.25	87.37
30	44.24	48.41	54.96	59.73
35	40.25	43.17	47.75	51.08
40	35.74	36.54	37.81	38.72
45	31.23	29.92	27.86	26.36
50	29.21	26.48	22.2	19.09
55	23.01	21.1	18.09	15.9
60	18	16.68	14.33	12.62
65	13.02	12.56	11.7	11.08
70	8.04	8.44	9.07	9.53
75	5.45	6.19	7.35	8.2
80	4.92	5.52	6.46	7.14
85	4.14	4.65	5.47	6.06
90	3.12	3.76	4.33	4.74
95	2.69	2.88	3.2	3.42
100	2.09	2.4	2.95	3.37

APPENDIX G : FREQUENCY ANALYSIS

Table G_1 : Frequency analysis of monthly precipitation for 1960-65 watershed degradation scenario

	Years								
Ppt,mm	1960	1961	1962	1963	1964	1965	Total	No of time equal.	P %
10	3	1	0	1	1	1	7	45	100
30	1	0	0	1	0	0	3	38	84.44
50	1	0	2	0	1	0	4	35	77.78
70	0	1	0	0	0	1	2	31	68.89
90	0	0	0	0	1	1	2	29	64.44
110	0	0	0	0	0	0	0	27	60
130	1	2	0	0	0	0	3	27	60
150	0	0	0	0	1	0	1	24	53.33
170	1	0	0	1	0	0	2	23	51.11
190	1	0	0	1	0	0	2	21	46.66
210	0	0	0	0	1	0	1	19	42.22
230	0	0	0	0	0	1	1	18	40
250	0	0	1	0	0	0	1	17	37.78
270	0	0	0	0	0	1	1	16	35.56
290	0	0	1	1	0	0	2	15	33.33
310	0	1	2	1	0	0	5	13	28.89
330	0	0	0	0	1	0	1	8	17.78
350	0	0	0	0	0	0	0	7	15.56
370	1	0	0	1	0	1	3	7	15.56
390	0	1	0	0	0	0	1	4	8.89
410	0	0	0	0	0	0	0	3	6.67
430	1	0	0	0	0	0	1	3	6.67
450	0	0	1	0	0	0	1	2	4.44
470	0	0	0	0	0	0	0	1	2.22
490	0	0	0	1	0	0	1	1	2.22
510	0	0	0	0	0	0	0	0	0

Table G_2 : Frequency analysis of monthly precipitation for 1965-75 watershed degradation scenario

	Years													
Ppt,mm	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Total	No of dys	P%
10	1	1	3	3	1	4	1	1	1	2	1	19	99	100
30	0	1	2	1	0	0	1	0	0	2	0	7	80	80.81
50	0	0	0	0	1							1	73	73.74
70	1	0	0	0	2	0	0	1	2	1	1	8	72	72.73
90	1	0	1	0	0	0	1	1	1	0	0	5	64	64.65
110	0	0	0	0	0	1	0	1	0	0	2	4	59	59.6
130	0	2	0	0	0	0	0	0	1	1	0	4	55	55.56
150	0	0	1	0	1	1	0	1	0	1	1	6	51	51.52
170	0	0	0	1	2	1	0	0	0	0	0	4	45	45.45
190	0	0	0	0	0	0	1	0	0	1	0	2	41	41.41
210	0	1	1	0	0	0	1	0	0	0	0	3	39	39.39
230	1	1	0	1	0	0	0	1	1	0	0	5	36	36.36
250	0	2	0	0	1	0	0	1	0	0	2	6	31	31.31
270	1	0	0	0	0	0	2	0	1	0	0	6	25	25.25
290	0	0	0	0	0	1	1	1	0	0	0	3	19	19.19
310	0	0	0	0	1	0	0	0	1	0	0	2	16	16.16
330	0	0	1	0	0	1	1	0	0	1	0	4	14	14.14
350	0	0	0	1	0	0	0	0	0	0	1	2	10	10.1
370	1	0	1	0	0	0	0	0	0	0	0	2	8	8.08
390	0	0	1	0	0	0	0	0	0	0	0	1	6	6.06
410	0	0	0	0	0	0	0	0	1	1	0	2	5	5.05
430	0	0	0	0	0	0	0	0	0	0	0	0	3	3.03
450	0	0	0	0	0	1	0	1	0	0	0	2	3	3.03
470	0	0	0	0	0	0	0	0	0	0	0	0	1	1.01
490	0	1	0	0	0	0	0	0	0	0	0	1	1	1.01
510	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table G_3 : Frequency analysis of monthly precipitation for 1975-86 watershed degradation scenario

Ppt,mm	Years 1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total	No of times	% time equalled
10	1	1	0	1	1	2	0	1	1	1	0	0	9	92	100
50	0	0	0	0	0	0	2	0	1	1	1	0	5	71	77.17
70	1	0	1	0	0	1	0	0	1	1	0	1	6	66	71.74
90	0	2	1	0	1	0	0	2	0	0	1	1	8	60	65.22
100	2	0	1	0	1	2	0	1	1	0	0	0	8	52	56.52
130	0	0	0	0	0	0	2	0	1	1	2	0	6	44	47.83
150	1	0	1	0	0	0	0	1	0	1	0	0	4	38	41.3
170	0	0	0	0	0	0	0	1	0	0	1	0	2	34	36.96
190	0	0	0	0	0	0	0	0	0	0	0	0	0	32	34.78
210	0	1	0	1	0	1	1	1	2	0	0	1	8	32	34.78
230	0	1	0	0	0	1	0	1	0	0	1	0	3	24	26.09
250	2	1	1	0	0	0	1	0	0	0	0	1	6	21	22.83
270	0	0	2	1	2	0	0	0	0	0	0	0	5	15	16.3
290	0	0	0	0	0	1	0	0	0	0	0	0	1	10	10.87
310	0	0	0	0	0	1	0	0	1	0	0	0	2	9	9.78
330	0	0	0	0	0	0	0	0	0	1	0	1	2	7	7.61
350	1	0	0	0	1	1	0	0	0	0	0	0	3	5	5.43
370	0	0	0	1	0	0	0	0	0	0	0	0	1	2	2.17
390	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.09
410	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1.09
430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table G_4 : Frequency analysis of monthly precipitation for 1986-92 watershed degradation scenario

Ppt,mm	Years 1986	1987	1988	1989	1990	Total	No of months equalled	% of time
10	0	0	0	1	1	2	34	100
30	2	1	0	0	1	4	32	94.12
50	0			1	1	2	28	82.35
70	0	0	0	2	1	3	26	76.47
90	1	1	1	0	1	4	23	67.65
110	0	0	2	1	0	3	19	55.88
130	0	0	0	1	2	3	16	47.06
150	0	1	1	0	0	2	13	38.23
170	0	0	2	0	0	2	11	32.35
190	0	2	1	0	0	3	9	26.47
210	1	0	0	0	0	1	6	17.65
230	0	0	0	0	1	1	5	14.71
250	1	0	0	1	0	2	4	11.76
270	0	0	0	0	0	0	2	5.88
290	0	0	0	0	0	0	2	5.88
310	0	1	0	0	0	1	2	5.88
330	0	0	0	0	0	0	1	2.94
350	1	0	0	0	0	1	1	2.94
370	0	0	0	0	0	0	0	0

Table G_5 : Frequency analysis of monthly watershed loss factor for 1960-1965 Mswiswi watershed degradation scenario

Watershed loss factor (WLF)	Years 1960	1961	1962	1963	1964	1965	Total	No of months WLF equalled	Probability of exceedance %
0.05	0	0	0	0	2	0	2	38	100
0.15	0	1	0	0	0	0	1	36	94.74
0.25	0	0	0	0	0	0	0	35	92.1
0.35	0	0	0	0	0	0	0	35	92.1
0.45	1	0	0	0	0	0	1	35	92.1
0.55	0	0	0	0	0	0	0	34	89.47
0.65	1	1	0	0	1	0	3	34	89.47
0.75	1	1	1	1	0	0	4	31	81.58
0.85	0	2	1	1	3	2	9	27	71.05
0.95	3	2	5	2	3	3	18	18	47.37
1.05	0	2	0	0	0	0	0	0	0

Table G_6 : Frequency analysis of monthly watershed loss factor for 1965-75 Mswiswi watershed degradation scenario

Watershed loss factor (WLF)	Year 1965	1966	1967	1968	1969	1970	1971	1972	1974	1975	Total	No of time equall	Probability of exceedance %
0.05	0	0	0	0	1	1	0	0	0	0	2	58	100
0.15	0	1	0	0	0	0	0	0	0	0	1	56	96.55
0.25	0	0	0	0	0	1	0	0	1	0	2	55	94.83
0.35	0	0	0	0	1	0	0	1	0	0	2	53	91.38
0.45	0	0	1	0	0	0	0	1	0	1	3	51	87.93
0.55	0	0	0	0	2	0	0	2	0	0	7	48	82.76
0.65	0	1	0	0	1	1	3	0	1	1	5	41	70.69
0.75	0	1	1	2	0	0	0	0	0	1	6	36	62.07
0.85	2	1	1	3	0	0	1	0	1	1	9	30	51.72
0.95	3	2	4	1	2	2	0	2	2	1	21	21	36.21
1.05	0	0	0	0	0	0	2	0	0	0	0	0	0

Table G_7 : Frequency analysis of monthly watershed loss factor for 1975-86 Mswiswi watershed degradation scenario

Watershed loss factor (WLF)	Years 1975	1976	1977	1978	1980	1981	1982	1984	1985	1986	Total	No of time (WLF) equalled or exceeded	Probability of exceedance %
0.05	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	2	1	3	55	100
0.25	0	0	0	0	0	0	0	0	0	0	0	52	94.54
0.35	0	0	0	0	0	0	0	0	0	0	0	52	94.54
0.45	1	1	0	0	0	1	1	1	2	0	7	52	94.54
0.55	0	1	0	0	0	0	0	0	0	3	3	45	81.82
0.65	1	0	0	1	0	2	0	0	0	0	4	42	76.36
0.75	1	0	3	0	2	0	0	1	0	0	7	38	69.09
0.85	1	2	0	0	1	3	3	0	0	1	11	31	56.36
0.95	1	1	3	2	4	1	3	2	2	1	20	20	36.36
1.05	0	0	0	0	0	0	0	0	0	0	0	0	0

Table G_1: Frequency analysis of monthly watershed loss factor for 1986-92 Mswiswi watershed degradation scenario

Watershed loss factor	Years							No of months WLF exceedance
	1986	1987	1988	1989	1990	Total	equalled	
0.05	0	0	0	0	0	0	0	0
0.15	1	0	0	1	0	2	26	100
0.25	0	0	0	0	0	0	24	92.31
0.35	0	0	0	0	0	0	24	92.31
0.45	0	0	1	0	1	2	24	92.31
0.55	3	0	2	0	0	5	22	84.62
0.65	0	1	0	0	1	2	17	65.38
0.75	0	2	0	0	0	2	15	57.69
0.85	0	1	3	2	2	8	13	50
0.95	1	2	0	1	1	5	5	19.23
1.05	0	0	0	0	0	0	0	0

APPENDIX H : REGRESSION ANALYSIS

Table H_1 : Regression analysis for runoff model for 1975-86 watershed degradation scenario

Probability of exceedance	Monthly runoff, mm	Ppt, mm	WLF	Log Q	Log P	Lg(WLF)
0.1	244.59	428.17	1.05	2.39	2.63	0.021
0.5	241.79	420.83	1.05	2.38	2.62	0.021
1	238.46	411.65	1.05	2.38	2.61	0.021
2.5	221.25	367.98	1.04	2.34	2.57	0.017
5	178.21	352.64	1.04	2.25	2.55	0.017
10	157.73	236.69	1.02	2.20	2.37	0.009
15	123.87	305.96	1.01	2.09	2.49	0.004
20	87.13	274.79	0.99	1.94	2.44	-0.004
25	74.25	258.67	0.98	1.87	2.41	-0.009
30	54.96	221	0.97	1.74	2.34	-0.013
35	47.75	187.98	0.95	1.68	2.27	-0.022
40	37.81	155.99	0.93	1.58	2.19	-0.032
45	27.86	138.67	0.91	1.44	2.14	-0.041
50	22.2	125	0.88	1.35	2.10	-0.056
55	18.09	113.5	0.86	1.26	2.05	-0.066
60	14.33	102	0.82	1.16	2.01	-0.086
65	11.7	90.51	0.78	1.07	1.96	-0.108
70	9.07	75.34	0.73	0.96	1.88	-0.137
75	7.35	57.99	0.66	0.87	1.76	-0.180
80	6.46	45.66	0.58	0.81	1.66	-0.237
85	5.47	38	0.53	0.74	1.58	-0.276
90	4.33	30.34	0.48	0.64	1.48	-0.319
95	3.2	22.22	0.24	0.51	1.35	-0.620
100	2.95	10	0.15	0.47	1.00	-0.824

Regression Output:

Constant		-3.186065
Std Err of Y Est		0.1146039
R Squared		0.9719171
No. of Observations		21
Degrees of Freedom		24
X Coefficient(s)	2.132562564	-1.688518
Std Err of Coef.	0.131111994	0.2775654

Q=P^2.132/(1534.616*(WLF)^1.689)

Regression Output:

Constant	-1.44921
Std Err of Y Est	0.186092
R Squared	
No. of Obs.	24
Degrees of Freedom	21
X Coefficient(s)	1.404307
Std Err of Coef.	0.086823

Q=0.036*P^1.404

Regression Output: Q-WLF

Constant	1.8000242
Std Err of Y Est	0.41289
R Squared	0.6181301
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	2.43365198
Std Err of Coef.	0.407816612

Table H_2 : Regression analysis for runoff model for 1986-92 watershed degradation scenario

Probability of exceedance	Monthly runoff, mm	Ppt, mm	WLF	Log Q	Log P	Lg(WLF)
0.1	267.99	369.32	1.05	2.43	2.57	0.021
0.5	265.55	366.6	1.04	2.42	2.56	0.017
1	263.03	363.2	1.05	2.42	2.56	0.021
2.5	243.47	352.99	1.04	2.39	2.55	0.017
5	203.65	315.99	1.02	2.31	2.50	0.009
10	188.95	193.33	1	2.28	2.29	0.000
15	142.15	255.98	0.97	2.15	2.41	-0.013
20	105.31	228.03	0.95	2.02	2.36	-0.022
25	87.37	204.67	0.93	1.94	2.31	-0.032
30	59.73	178.23	0.91	1.78	2.25	-0.041
35	51.08	160.98	0.9	1.71	2.21	-0.046
40	38.72	146	0.88	1.59	2.16	-0.056
45	26.36	134.67	0.87	1.42	2.13	-0.060
50	19.09	123.33	0.85	1.28	2.09	-0.071
55	15.9	112	0.78	1.20	2.05	-0.108
60	12.62	103	0.72	1.10	2.01	-0.143
65	11.08	94.5	0.65	1.04	1.98	-0.187
70	9.53	84.67	0.63	0.98	1.93	-0.201
75	8.2	73.33	0.6	0.91	1.87	-0.222
80	7.14	57.99	0.57	0.85	1.76	-0.244
85	6.06	43.5	0.55	0.78	1.64	-0.260
90	4.74	37	0.48	0.68	1.57	-0.319
95	3.42	27.01	0.22	0.53	1.43	-0.658
100	3.37	10	0.15	0.53	1.00	-0.824

Regression Output:

Constant		-3.971823
Std Err of Y Est		0.2091271
R Squared		0.9101185
No. of Observations		24
Degrees of Freedom		21
X Coefficient(s)	2.502295128	-1.904884
Std Err of Coef.	0.315950709	0.5962349

Q=P^2.502/(9375.62*WLF^1.905)

Regression Output:

Constant	-1.72034
Std Err of Y Est	0.249072
R Squared	0.866431
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	1.555212
Std Err of Coef.	0.130186

Q=0.019P^1.555

Regression Output:

Constant		1.8910181
Std Err of Y Est		0.4079677
R Squared		0.6416523
No. of Observations		24
Degrees of Freedom		22
X Coefficient(s)	2.525633951	
Std Err of Coef.	0.402403283	

Table H_3 : Regression analysis for runoff model for 1960-65 watershed degradation scenario

Probability of exceedance	Monthly runoff, mm	Ppt, mm	WLF	Log Q	Log P	Log WLF
0.1	191.93	509.10	1.05	2.28	2.71	0.021
0.5	187.44	505.50	1.05	2.27	2.70	0.021
1	183.17	501.00	1.05	2.26	2.70	0.021
2.5	171.26	467.48	1.04	2.23	2.67	0.017
5	120.98	444.98	1.04	2.08	2.65	0.017
10	84.49	386.67	1.03	1.93	2.59	0.013
15	82.74	371.68	1.02	1.92	2.57	0.009
20	46.23	326.00	1.01	1.66	2.51	0.004
25	44.72	417.00	1.00	1.65	2.62	0.000
30	44.24	305.00	0.99	1.65	2.48	-0.004
35	40.25	275.02	0.98	1.60	2.44	-0.009
40	35.74	230.00	0.96	1.55	2.36	-0.018
45	31.23	197.48	0.95	1.49	2.30	-0.022
50	29.21	174.99	0.94	1.47	2.24	-0.027
55	23.01	145.00	0.92	1.36	2.16	-0.036
60	18.00	130.00	0.90	1.26	2.11	-0.046
65	13.02	85.48	0.88	1.11	1.93	-0.056
70	8.04	67.50	0.85	0.91	1.83	-0.071
75	5.45	56.25	0.81	0.74	1.75	-0.092
80	4.92	43.33	0.77	0.69	1.64	-0.114
85	4.14	29.28	0.71	0.62	1.47	-0.149
90	3.12	22.85	0.53	0.49	1.36	-0.276
95	2.69	16.43	0.15	0.43	1.22	-0.824
100	2.09	10.00	0.05	0.32	1.00	-1.301

Regression Output:

Constant	-1.11006289
Std Err of Y Est	0.158006609
R Squared	0.939577224
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	1.165730177
Std Err of Coef.	0.063026153

Q=0.078*P^1.166

Regression Output: Q-WLF

Constant	1.580120038
Std Err of Y Est	0.485073527
R Squared	0.430537254
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	1.348829672
Std Err of Coef.	0.330729597

Table H_4 : Regression analysis for runoff model for 1965-75 watershed degradation scenario

Probability of exceedance	Monthly runoff, mm	Ppt, mm	WLF	Log Q	Log P	Lg(WLF)
0.1	213.41	508.02	1.05	2.33	2.71	0.021
0.5	208.56	500.10	1.05	2.32	2.70	0.021
1	204.67	490.10	1.05	2.31	2.69	0.021
2.5	190.70	455.25	1.04	2.28	2.66	0.017
5	143.23	410.50	1.04	2.16	2.61	0.017
10	114.80	351.00	1.02	2.06	2.55	0.009
15	98.74	321.48	1.01	1.99	2.51	0.004
20	62.13	287.33	0.99	1.79	2.46	-0.004
25	56.20	270.83	0.98	1.75	2.43	-0.009
30	48.41	254.32	0.97	1.68	2.41	-0.013
35	43.17	235.39	0.95	1.64	2.37	-0.022
40	36.54	203.96	0.93	1.56	2.31	-0.032
45	29.92	172.23	0.89	1.48	2.24	-0.051
50	26.48	155.01	0.86	1.42	2.19	-0.066
55	21.10	130.77	0.82	1.32	2.12	-0.086
60	16.68	108.40	0.77	1.22	2.04	-0.114
65	12.56	89.13	0.72	1.10	1.95	-0.143
70	8.44	76.77	0.66	0.93	1.89	-0.180
75	6.19	46.44	0.61	0.79	1.67	-0.215
80	5.52	32.29	0.57	0.74	1.51	-0.244
85	4.65	25.63	0.51	0.67	1.41	-0.292
90	3.76	20.42	0.39	0.58	1.31	-0.409
95	2.88	15.21	0.19	0.46	1.18	-0.721
100	2.40	10.00	0.05	0.38	1.00	-1.301

Regression Output:

Constant		-1.715649
Std Err of Y Est		0.1167577
R Squared		0.9693489
No. of Observations		24
Degrees of Freedom		21
X Coefficient(s)	1.45574654	-0.543287
Std Err of Coef.	0.087258623	0.1520614

$Q=P^{1.456}/(51.88*(WLF)^{0.543})$

Regression Output:

Constant	-1.071555
Std Err of Y Est	0.1446464
R Squared	0.9507174
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	1.192445161
Std Err of Coef.	0.057882616

$Q=0.085P^{1.192}$

Regression Output: Q-WLF

Constant	1.7093987
Std Err of Y Est	0.4306723
R Squared	0.5631097
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	1.59926331
Std Err of Coef.	0.300329706

APPENDIX I: CUMULATIVE WATER YIELD DEFICIT (EXCESS) FOR DETERMINATION OF WATERSHED DEGRADATION SCENARIOS

Year	Annual water yield, Mm^3	$X_i - X_c$	Sum $(X_i - X_c)$
1960	23.46	-20.61	-20.61
1961	35.14	-8.93	-29.54
1962	20.73	-23.34	-52.88
1963	23.12	-20.95	-73.83
1964	22.14	-21.93	-95.76
1965	24.60	-19.47	-115.23
1966	60.40	16.33	-98.90
1967	60.27	16.20	-82.70
1968	88.0	43.93	-38.77
1969	32.53	-11.54	-50.31
1970	50.8	6.73	-43.58
1971	45.23	1.16	-42.42
1972	65.44	21.37	-21.05
1974	71.77	27.70	6.65
1975	44.90	0.83	7.48
1976	37.85	-6.22	1.26
1977	27.07	-17.00	-15.74
1978	46.45	2.38	-13.36
1980	14.95	-29.12	-42.48
1981	24.97	-19.10	-61.58
1982	15.85	-28.22	-81.80
1984	15.48	-28.59	-118.39
1985	39.19	-4.88	-123.27
1986	36.76	-7.31	-130.58
1987	NR	NR	
1988	106.21	62.14	-68.44
1989	49.18	5.11	-63.33
1990	38.71	-5.36	-68.69
1991	53.44	9.37	-59.32
1992	103.39	59.32	0.00

* Truncation level, X_c = 44.07 Mm_3
* NR, means no record

APPENDIX K : SIGNIFICANT DIFFERENT TEST

Table K1: Testing if there is significant difference between observed and simulated April monthly runoff

	Observed	Simulated		
Year	X_o	X_s	$(X_o-X_{om})^2$	$(X_s-X_{sm})^2$
1963	5.68	3.20	0.34	1.00
1964	0.78	0.22	30.03	15.84
1965	2.74	0.90	12.39	10.89
1966	7.38	4.95	1.25	0.56
1967	12.08	8.90	33.87	22.09
1968	7.51	5.21	1.56	1.02
1969	5.57	3.33	0.48	0.76
1970	5.38	2.93	0.77	1.61
1971	7.12	5.62	0.74	2.02
1973	11.37	7.60	26.11	11.56
1974	13.39	10.89	50.84	44.76
1975	9.18	6.20	8.53	4.00
1976	5.30	1.75	0.92	6.00
1977	8.58	6.10	5.38	3.61
1980	4.30	5.12	3.84	0.85
1981	5.08	3.04	1.39	1.35
1982	8.25	5.83	3.96	2.66
1984	0.66	0.90	31.36	10.89
1985	9.50	7.38	10.50	10.11
1986	1.20	0.40	25.60	14.44
1987	6.58	4.18	0.10	0.00
1988	6.62	4.16	0.13	0.00
1989	3.15	1.04	9.67	9.99
1990	2.89	0.95	11.36	10.56
Sum	150.29	96.60	271.13	186.56

X_{om} = 150.29/24 = 6.26, S_o^2 = Sqr(271.13/23) =3.43

X_{sm} = 100.80/23 = 4.20, S_s^2 = Sqr(186.56/23) = 2.85

The calculated t is computed from equation:

$$t=\frac{X_{om}-X_{sm}}{\sqrt{\frac{(n_o-1)S_o^2+(n_s-1)S_s^2}{n_o+n_s-2}*\frac{n_o+n_s}{n_o.n_s}}} \qquad (34)$$

Where, X_{om} and X_{sm}, are mean of observed and simulated samples, respectively,

S_o^2 and S_s^2 are estimated variances of observed simulated samples respectively.

To test whether there is significant difference between observed and simulated runoff of april month, the means of observed and simulated are tested at 95 percent confidence interval. The hypotheses are :

$$H_0: D=\mu_o-\mu_s=0$$

$$H_1: \mu_o - \mu_s \neq 0$$

From equation (34) calculated t = 0.83

The critical value is between

$-t_{0.025}^{(24+24-2)} = -t_{0.025}^{46} = 2.02$

$t_{0.025}^{(24+24-2)} = t_{0.025}^{46} = 2.02$

Since the calculated t=0.83< t* then the means for observed and simulated are not significantly different at 95 percent confidence interval.

Table K_2: Testing if there is significant difference between observed and simulated monthly baseflow in April

	Observed	Simulated		
Year	X_o	X_s	$(X_o-X_{om})^2$	$(X_s-X_{sm})^2$
1963	1.21	1.85	0.40	0.16
1964	0.69	0.84	1.32	1.99
1965	1.17	1.84	0.45	0.17
1966	2.06	4.11	0.05	3.46
1967	3.20	5.17	1.85	8.53
1968	5.13	3.63	10.82	1.90
1969	1.54	2.35	0.09	0.01
1970	0.91	1.44	0.86	0.66
1971	1.87	2.26	0.00	0.00
1973	1.57	2.06	0.07	0.04
1974	4.50	3.32	7.08	1.14
1975	2.74	3.31	0.81	1.12
1976	1.94	2.14	0.01	0.01
1977	1.83	3.72	0.00	2.16
1980	0.93	1.88	0.83	0.14
1981	1.38	0.78	0.21	2.16
1982	1.23	1.84	0.37	0.17
1984	0.98	0.71	0.74	2.37
1985	1.12	2.74	0.52	0.24
1986	1.11	0.91	0.53	1.80
1987	1.09	2.64	0.56	0.15
1988	2.67	2.52	0.69	0.07
1989	1.89	1.00	0.00	1.56
1990	1.44	0.83	0.16	2.02
Sum	44.20	53.89	28.43	32.03

X_{om} = 44.20/24 = 1.84, S_o^2 = Sqr(28.43/23) =1.11

X_{sm} = 53.89/23 = 2.25, S_s^2 = Sqr(32.03/23) = 1.18

Substituting the above value in equation (31), we got t= -0.80 and t-tabulated = 2.02

The means for observed and simulated baseflow are not significantly difference at 95 percent confidence interval.