IMPACTS OF BEST MANAGEMENT PRACTICES (BMPS) ON WATER QUANTITY AND QUALITY OF MALEWA BASIN

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Abstract

This paper evaluated the impacts of best management practices (BMPs) on water quality and quantity of Malewa selected subbasins. Soil and Water Assessment Tool model was used in evaluating the effects of implementing BMPs. The model was calibrated and validated before doing BMPs scenarios of changing filter widths from 0 to 5m to 10m and altering the USLE-P factor from default value of (no conservation measure) to 0.65 and 0.1 respectively. The two scenarios were done independently. From the results, it was observed that filter strips were having varying effectiveness at reducing overland flow, sedimentation, and removing nutrients. The hydrologic benefit of riparian buffers increases with width. Considerable reductions in sediment concentrations occur when 5m wide filter strips are simulated. However, increasing the filter strips by an additional 5m (total 10 m) does not produce the same level of reductions as was observed for the 0 to 5m condition. This suggests that benefits from implementing filter strips will taper off for further increases in filter width. Reductions were slightly higher for sub-with moderate slope gradient compared to sub-basins with steep slopes. Also headwater sub-basins recorded greater reductions in sediment exports (e.g., 17, 13) compared to sub-basins located downstream (e.g., 23 and 19). Clearly greater improvements in water quality could be achieved by targeting headwater sub-basins. The impact of simulating filter strips on the sediment load at the main watershed outlet was also determined. The 5m filter scenarios produces a 17% reduction in sediment load, whereas doubling the filter widths only decreases the load by an additional 5%.

1.0 Introduction

Best Management Practices (BMPs) are recommended methods, structures, and practices designed to prevent or reduce water pollution while maintaining economic returns. The BMPs concept deals specifically with nonpoint source pollution, such as runoff from agricultural fields. Implicit within the BMPs concept is a voluntary, site-specific approach to water quality problems. Many of these methods are already standard practices, known to be both environmentally and economically sustainable.

Best Management Practices prevent pollution from agricultural operations. Plant nutrients, bacteria, sediment and agricultural chemicals can be controlled so that pollution of surface and ground water does not occur and limit the use for drinking, aquatic life and recreation. Odor, vectors, and other nuisances can also be minimized by adequate BMP's. Implementation of Best Management Practices (BMPs) is a conventional approach for controlling nonpoint sources of sediments and nutrients. However, implementation of BMPs is rarely followed by a good long-term data monitoring program in place to study how effective they have been in meeting their original goals. Long-term data on flow and water quality within watersheds, before and after placement of BMPs, is not generally available. Therefore, evaluation of BMPs (especially new ones that have had little or no history of use) must be necessarily conducted through watershed models.

The availability and quality of freshwater supplies for human and ecological needs are critical factors influencing the health and livelihoods of all people in a nation. Continued growth in human population and water use, continued degradation of water supplies by contamination, and greater recognition of the legitimate needs for freshwater in order to support critical ecosystem functions will lead to increasing scarcity and conflict over freshwater supplies in coming years.

Effective hydrological modeling of watersheds is an essential tool in the management of land degradation and its off-site impacts, such as those associated with salinity and nutrient problems. Various methods have been used in the past to model processes and responses in catchment hydrology. Catchment hydrology models can be considered crudely as either, physical, conceptual or empirical. Each of these modeling approaches suffers from certain inadequacies (Wheater *et al*., 1993.)

The effects of land use on water resources vary according to local conditions. The assessment is difficult due to large delays between cause and effect and the interference between anthropic and natural impacts caused by, e.g., climatic changes. These limitations make it difficult to draw general conclusions about the relations between land and water use in watersheds. However, some experiences show that land management impacts on watershed hydrology and sedimentation are observed more clearly in small-scale watersheds of about tens of square kilometers. Some land management effects on water quality can be observed also at larger scales. In recent years there has been an increasing trend to predict hydrologic changes brought about by land cover transformations in the tropics by robust models employing data obtained during relatively short but intensive measuring periods (Shuttleworth, 1990 and Institute of Hydrology, 1990).

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2.0 Overview of the Study Area

Malewa basin lies between the two flanks of the Eastern or Gregory Rift Valley, with the Aberdares Mountains and Kinangop plateau on the east and the Mau Escarpment on the west. The Malewa basin is situated in the central Rift Valley, Naivasha District in Kenya about 100 km northwest from Nairobi (Figure 1). Its geographical position lies between 36°15′E-36°30′E longitude and 00°40′S-00°53′S latitude. The altitude ranges from 1900-3980m.a.m.s.l.

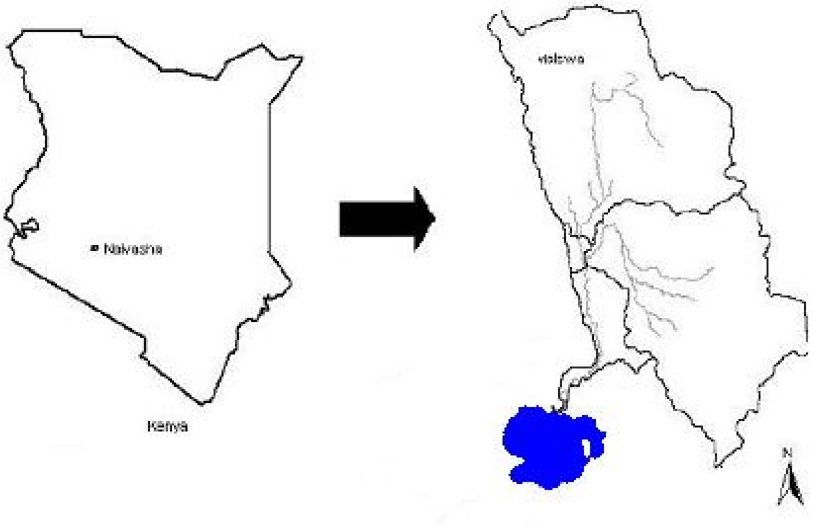

Figure 1: Map of the study area (Lake Naivasha-Malewa basin).

2.1 Climate

The Malewa basin belongs to a semi-arid type of climate. The rainfall distribution has a bimodal character (Figure 2). The long term spatial distribution of rain varies from 600mm at Naivasha town to 1700mm at the slopes of the Nyandarua Mountains the Kinangop plateau experiences a yearly rainfall from 1000mm and 1300mm (Becht and Higgins 2003). Longer rainy season occurs in March-May and short rainy seasons occur in October-November (Kamoni, 1988). February, July and December are the driest months of the year. The lowest temperatures are experienced in July, while the highest temperatures occur in March. The potential evaporation is about twice the annual rainfall in the semi arid area while in the upper basin humid areas, rainfall exceeds potential evaporation in most parts of the year (Farah, 2001). The annual temperature range is approximately from 8^0C to 30^0C.

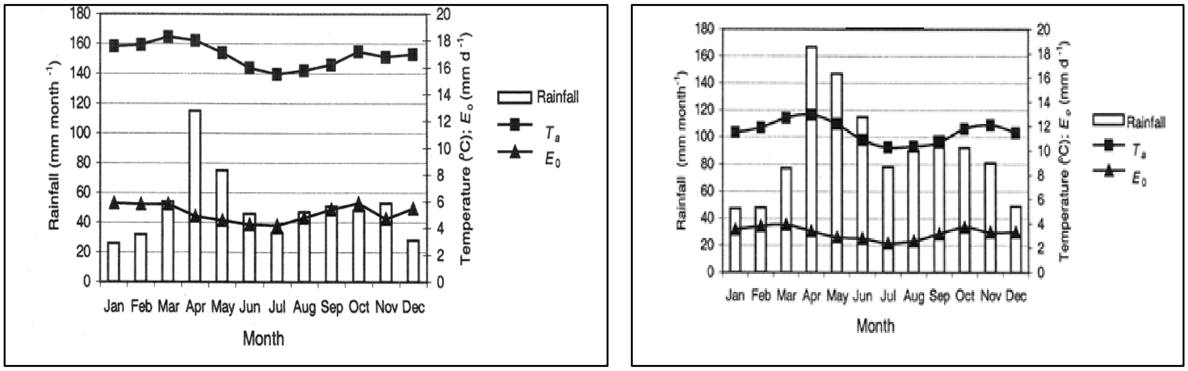

Figure 2: Monthly average rainfall, average daily temperature (1931-1983) and average daily reference E_o (1974-1983) at Naivasha town at altitude 1906 m and at North Kinangop at 2620 m (Source: Farah, 2001)

2.2 Vegetation

Landcover in the basin is greatly influenced by rainfall. The vegetation can be broadly classified into:

- Forest,
- Scrub/Bush-land/native,
- Bare/range brush/moorland,
- Grassland/scrubland, and
- Agricultural land (small intensive/sparse)

The land cover of the basin is broadly categorized into four groups, namely Agriculture, Grass, Bush/scrub land and Forest. In the Nyandarua ranges, predominant land cover classes are forest and crops. The main crops are maize, potatoes and wheat. In addition there are many other vegetables grown by smallholder farmers in the middle part of the basin. In the lower catchments, there are extensive areas of grass/scrubland and bush land, which are used for livestock grazing (Muthawatta, 2004).

2.3 Soils

The soils in Malewa basin can be described as complex due to the influence of extensive relief variation, volcanic activity and underlying bedrocks (Sombroek *et al,* 1980). Based on studies conducted in the area (Sombroek *et al* 1980, Siderius, 1998; Atkilt, 2001; and Nagelhout, 2001) soils can be grouped into three (3) groups such as; 1) soils developed from lacustrine deposits; 2) volcanic; and 3) lacustrine-volcanic. These soils are highly susceptible to both erosion and compaction (Kiai and Mailu, 1998). Prominent soil degradations in the area are due to wind and water erosion, sealing and compaction (Nagelhout, 2001). The fragility of the area and various human activities seems to accelerate land degradation in the west and southern area of the basin (Hennemann, 2001). From the Kenya soil terrain (SOTWIS Ver. 1), the soils of the study area can be classified into 10 different soil categories based on the FAO classification (Figure 3).

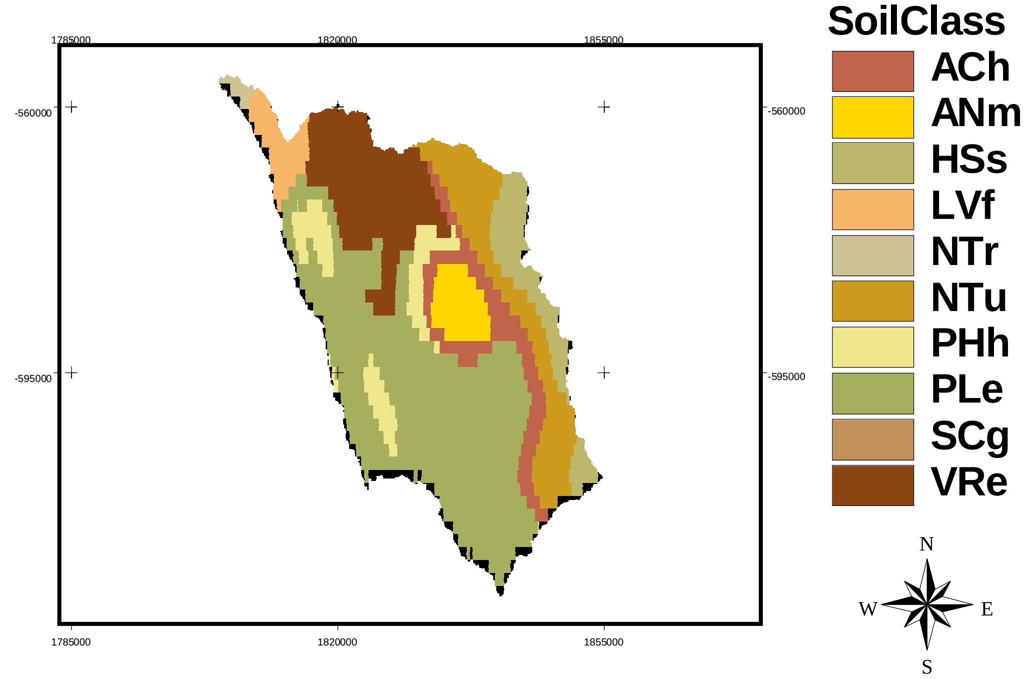

Figure 3: Soil distribution in study area

2.4 The Drainage Networks

The Malewa River Basin, including the Turasha river basin comprises an area of 1705 Km^2 which is approximately 50% of the larger Lake Naivasha Basin (3387Km^2). Drainage into the Malewa starts among the steep forested eastern slopes from the Kinangop plateau (2483m a.m.s.l.) and the Aberdares (3960+m a.m.s.l.) where the average annual rainfall is 1087.5mm (Salah, 1999). Initial flow takes place in a westerly direction via a number of steeply graded tributaries that, at the lower slopes of the range, develops into four main tributaries namely, Mugutyu, Turasha, Kitiri, and Mukungi. All flow north-south before turning west and joining the River Malewa. River Turasha is the most important tributary and joins the Malewa approximately 8km east of Gilgil town (Figure 4). The tributaries of the Malewa river forms a very dense dendritic drainage pattern except in the Kipipiri area where they have a radial flow pattern due to the conical shape of the volcanic Kipipiri range (Graham, 1998). River Wanjohi tributary and Malewa tributary flow northward before turning west the south from Ol Kalou.

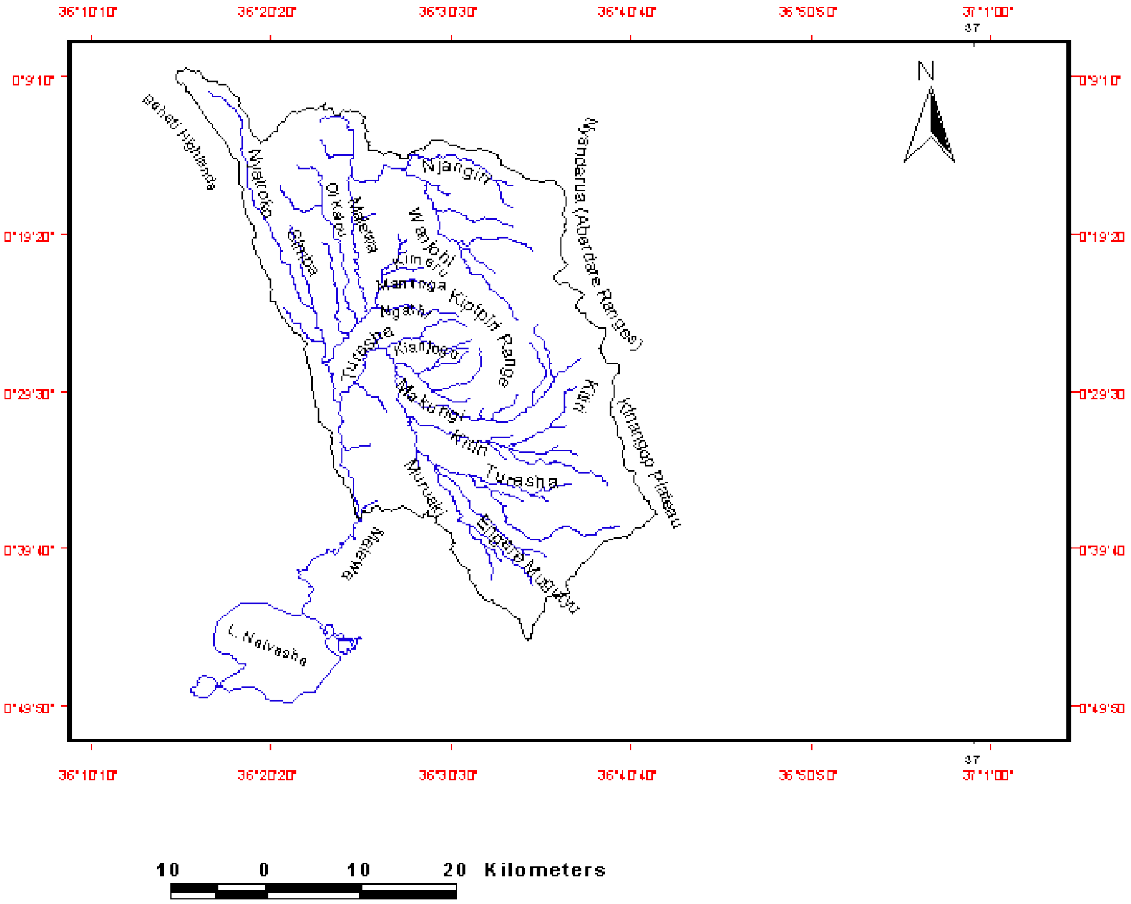

Figure 4: The Drainage Pattern of Malewa Watershed

3.0 Methods and Analysis

3.1 Hydrologic Model

For this study, the Soil and Water Assessment Tool (SWAT) was chosen The Soil and Water Assessment Tool is a river basin model that was developed for the USDA Agricultural Research Service, by Blackland Research Center in Texas (http://www.brc.tamus.edu/blackland/. Figure 5 presents a diagram of the SWAT process.

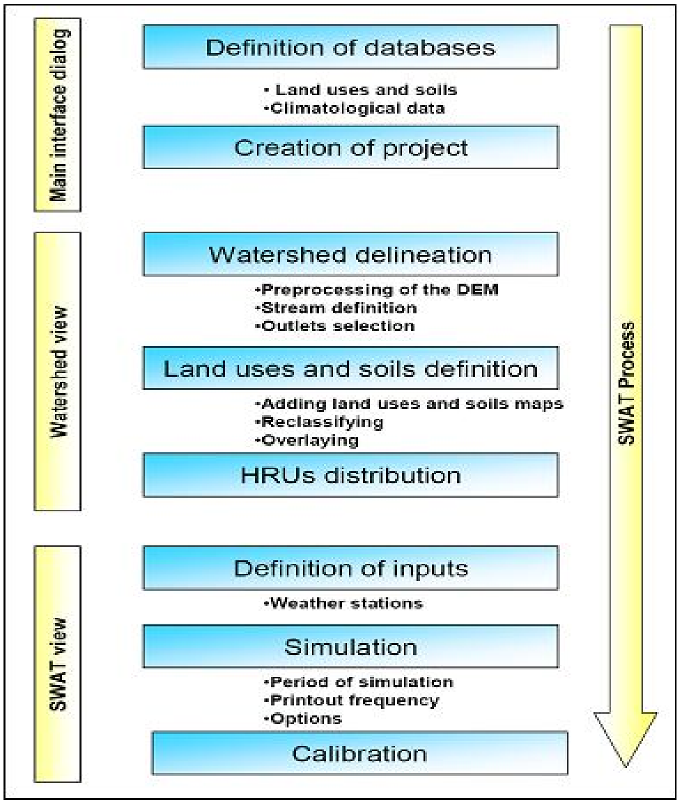

Figure 5: Representation of the SWAT model process

3.1.1 Input Data

Available data that were used for modeling are depicted in Table 1.

Table 1: Model input data sources for the Malewa Watershed

Data Types	Scale	Source	Data description/properties
Topo-sheets	1:50,000 and	Survey of Kenya	Boundary, drainage, geo-referencing
Soils (KENSOTER SOTWIS version 1)	1:1M	ISRIC	Soil physical properties e.g. bulk density, texture, saturated
Land use	1:250,000	1980 Landsat data by the Japan International Co-operation Agency, JICA, National Water	Land use classification valid for 1980
Weather		KMD	Daily precipitation and temperature,(9036002, 9036025, 9036054, 9036062, 9036183, 9036241, 9036281, 9036290,
Stream flow		Ministry of water and Irrigation	Daily stream flow (2GB01, 2GB03, 2GB04, 2GB05, 2GB07, 2GC04, 2GC05, 2GC07) for a period starting
BMP			Pre- and post-management

3.2 Modeling Process

The preliminary step was the definition of the databases (dbf tables) i.e. soil and land use parameters, and climatological data. Each table had to be defined clearly using the nomenclature provided in the SWAT user's manual. The climatological data were added in different files presenting each parameter and the location of their meteorological station. Table 2 represents the look-up table for the land use database. The land use mapped in the shapefile is linked to default categories present in SWAT.

Table 2: Relation between the land use map and the SWAT database

Land use shapefile	SWAT database
Forests, woodland	FRST Forest-Mixed
Agricultural Land	AGRL Agricultural Land – Generic
Infrastructures	UINS Institutional
Heath land, Brush land,	RNGB Range – Brush
Residential	URMD Residential – Medium Density
Marshland, peat bog	WETN Wetlands – Non Forested
Water	WETN Wetlands – Non Forested
Rocks	RNGB Range – Brush
Sands and Pebbles	FRST Forest-Mixed

The land use 'Water' exists in the SWAT database but it is advisable to use Wetlands because this special land use could create errors in the computation of the hydrological network (Renaud, 2004).

In this study, a yearly/monthly and daily printout on the period 1972 – 2003 was used. From the 1st Precipitation of January 1972, to the 31st Precipitation of December 2003, the outputs were then fully simulated. The outputs of SWAT are in different types: grids, shape files and tables. The results are presented in four main tables:

- Summary output file
- HRU output file
- Sub-basin output file
- Main channel/reach output file.

3.3 Sensitivity Analysis

Large complex watershed models contain hundreds of parameters that represent hydrologic and water quality processes in watersheds. Model predictions are more sensitive to perturbation of some input parameters than others, even though the insensitive parameters may bear a larger uncertain range. Thereby, adjustment of all model parameters for a given study area not only is cumbersome, but is not essential. Sensitivity analysis was done through the SWAT model sensitivity analysis tool. The observed flow data used was at the basin outlet 2GB01. Table 3 show amongst many SWAT parameters that are adjusted during sensitivity analysis process

Table 3: SWAT Parameters

	Parameter	**Description**	Min	Max	Units	SWAT
1	CN2	Initial SCS runoff curve number for moisture condition II	35	98		MGT
2	SLOPE	Average slope steepness	0	0.6	M/m	HRU
3	SLSUBBS	Average slope length	10	150	m	HRU
4	ESCO	Soil evaporation compensation factor	0	1		HRU
5	CH-N1	Manning’s “n” value for tributary channels	0.008	30		SUB
6	CH-S1	Average slope of tributary channels	0	10	m/m	SUB
7	CH-K1	Effective hydraulic conductivity in tributary channel alluvium	0	150	Mm/hr	SUB
8	CH-N2	Manning “n’ value for the main channel	0.008	0.3		RTE
9	CH-S2	Average slope of the main channel along the channel	0	10	m/m	RTE
10	CH-K2	Effective hydraulic conductivity in main channel alluvium	0	150	Mm/hr	RTE
11	GWQMN	Threshold depth of water in shallow aquifer for return flow to occur	0	5000	Mm	GW
12	ALPHA-	Base flow alpha factor	0	1	Days	GW
13	GW-	Ground water delay time	0	500	Days	GW
14	GW-	Ground water “revap” time	0.02	0.2		GW
15	SOL-AWC	Available water capacity of the soil layer	0	1	Mm/m	SOL
16	CH-EROD	Channel erodibility factor	0	0.6	Cm/hr/p	RTE
17	CH-COV	Channel cover factor	0	1		RTE
18	SPCON	Linear coefficient for calculating maximum sediment re-entrained	0.001	0.01		BSN
19	SPEXP	Exponent	1	1.5		BSN
20	PRF	V peak rate adjustment factor for sediment routing in channel network	0	2		BSN
21	USLE-P	USLE equation support practice factor	0.1	1		MGT
22	USLE-C	Maximum value of USLE equation for cover factor for water erosion	0.001	0.5		CROP DAT
23	SOL-LABP	Initial soluble P concentration in soil layer	0	100	Mg/kg	CHM
24	SOL-	Initial soluble P concentration in soil layer	0	4000	Mg/kg	CHM
25	SOL-	Initial NO3 concentration in soil layer	0	5	Mg/kg	CHM
26	SOL-	Initial organic N concentration in soil layer	0	1000	Mg/kg	CHM
27	RS1	Local algae settling rate at 20^{0c}	0	2	m/day	SWQ
28	RS2	Benthic (sediment) source rate for dissolved P in the reach at 20^{0c}	0.001	0.1	Mg/m^2day	SWQ
29	RS4	Rate coefficient for organic N settling in the reach of 20^{0c}				
30	RS5	Organic P settling rate in the reach at 20^{0c}				

31	BC4	Rate constant for mineralization of P to dissolve P in the reach at 20^{0c}				
32	A10	Ratio of chlorophyll –a to algae biomass				
33	A11	Fraction of algal biomass that is nitrogen				
34	A12	Fraction of algal biomass that is phosphorous				
35	RHOQ	Algal respiration rate at 20^{0c}				
36	K-P	Michaelis menton rate saturation constant for				

3.3.1 Model Calibration

Calibration of a watershed model is essentially the exercise of adjusting model parameters such that model as described by Beck *et al*. (1997):

- soundness of mathematical representation of processes,
- sufficient correspondence between model outputs and observations, and
- Fulfillment of the designated task.

Procedure provided by (Santhi *et al*., 2001b) was followed.

Simulation runs were conducted on a daily/monthly basis to compare the modeling output with the corresponding observed discharge. The calibration considered fourteen model parameters that can be summarized in three groups: (1) Parameters that govern surface water processes, including curve number (CN), soil evaporation compensation factor (ESCO), plant uptake compensation factor (EPCO), and available water capacity of the soil layer (SOL_AWC; (2) Parameters that control subsurface water processes, including capillary coefficient from groundwater (GW_REVAP), groundwater delay (GW_DELAY), and deep aquifer percolation fraction (RCHRG_DP); And (3) parameters that influence routing processes, including Manning's roughness coefficient in main channel routing (CH_N(2)) (Neitsch *et al*., 2002). One parameter was adjusted while others were kept unchanged.

3.3.2 Model validation

Data for a period of twenty-one years from January 1st, 1981 to December 31st, 1995 was used for validating the SWAT model for the Malewa River Basin.

3.3.3 Model Evaluation Criteria

The accuracy of SWAT simulation results was determined by examination of the coefficient of determination (R^2) and the Nash and Sutcliffe model efficiency coefficient (E_{NS}) (Nash and Sutcliffe, 1970). The R^2 value indicates the strength of the linear relationship between the observed and simulated values. The E_{NS} simulation coefficient indicates how well the plot of observed verse simulated values fits the 1:1 line. The E_{NS} can range from 2:1 to 1:1, with 1 being a perfect agreement between the model and real data (Santhi *et al*., 2001). E_{NS} is defined equation 3.1 as

$$\mathbf{E_{NS} = 1 -} [\{\sum_{i=1}^{n}(Measured_i - simulated_i)^2\}/\sum\ (measured_i - \frac{1}{n}\sum_{i=1}^{n} measured_i)^2] \qquad \textbf{Equation 3.1}$$

E_{NS} values range from 1.0 (best) to negative infinity. E_{NS} is a more stringent test of performance than R^2 and is never larger than r^2. E_{NS} measures how well the simulated results predict the measured data relative to simply predicting the quantity of interest by using the average of the measured data over the period of comparison. A value of 0.0 for E_{NS} means that the model prediction are just as accurate as using the measured data average to predict the measured data. E_{NS} value less than 0.0 indicate the measured data average is better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average. The simulation results were considered to be good if $E_{NS} \geq 0.75$, and satisfactory if $0.36 \leq E_{NS} \leq 0.75$ (Van Liew and Garbrecht, 2003).

3.4 Scenario Analysis

The following scenarios (Table 4) were adopted for the study of implementing best management practices (BMPs) on Geta and Wanjohi subbasins of Malewa.

Table 4: Scenarios Adopted for the BMPs on Wanjohi and Geta subbasins

1	Best Management practice	This scenario involved implementing two BMP. a) Filter strip (0, 1, 5, 10 m edge). This scenario involved altering the filter width from no filter width 0m to 1, and running the scenario, then 1m, 5m, and 10m respectively. Each scenario was compared with base scenario 0m b. Contours (P=0.1, P=0.65, and P=1). This scenario involved implementing contouring practices. In order to achieve this, the P in the support practice factor in USLE equation was modified from base condition 1 with no erosion control to erosion controlled structure with USLE-P value of 0.1, and 0.65 respectively.

4.0 Results and Discussions

Table 4 gives the scenarios adopted in evaluating the impacts of implementing BMPs in some selected subbasins of Malewa basin namely Geta and Wanjohi subbasins.

Table 4: Best Management Practices (BMPs) scenarios adapted for studying Impacts of Land-use change on Malewa Watershed.

BMP	**Base**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Filter strip	Base Filter	Filter width	Filter width	Filter width	Filter width (0	Filter width (0
Contour farming	Base USLE_P P=1	USLE_P P=1	USLE_P P=1	USLE_P P=1	USLE_P P=0.1	USLE_P P=0.65

Note: P is the support practice factor in USLE equation. Numerical values of *P-USLE* for these practices (Support practices include contour tillage, strip cropping on the contour and terrace systems) are given in Wischmeier and Smith, (1978) and reiterated by Neitsch *et al*., (2002) as used in the SWAT.

4.1 Impacts of Best Management Practices on Water Quantity and Quality

4.1.1 Effects of BMPs on Streamflow

The effect of implementing the best management practices (BMPs) on runoff volume and streamflow at the outlets of the two selected target areas are presented in Figures 6 for Wanjohi sub-basin and Figure 4.2 for Geta sub-basin respectively. USLE_P was modified to represent parrallel terrace/contouring with P value set at 0.1 and 0.65, filter strip was represented in the model by modifying filter width to 1 m, 5 m and 10 m. In the study area there are neither installed BMPs nor existing ones nor any data for analysis, hence it necessitated the use of SWAT model for simulating the impacts of implementing the BMPs on the selected priority sub-basins.

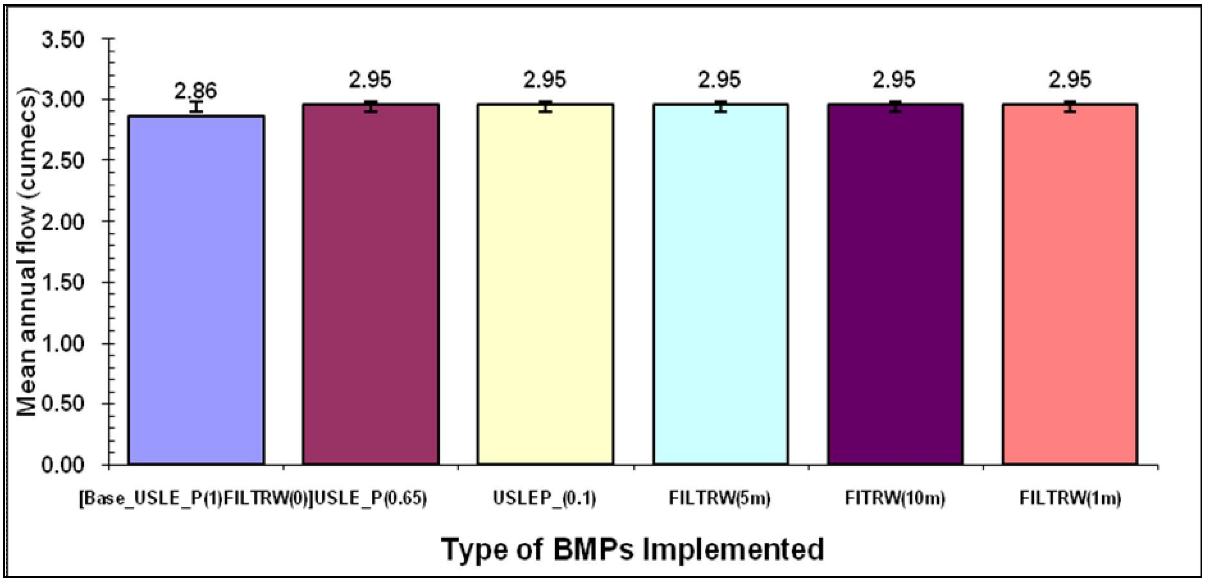

Figure 6: Impacts of BMPs on Streamflow at Wanjohi area
(Error bars with standard deviation)

The results shows that with the installation of BMPs in the Wanjohi catchment, streamflow increased from a mean of 2.86 cumecs in base scenario to 2.95 cumecs with all the BMPs installed in Wanjohi sub-basin. The results from Geta catchment (Figure 7) are however completely the opposite. The implementation of BMPs resulted in a reduction of streamflow though marginally compared to base scenario i.e. from 3.1 to 3.0 cumecs.

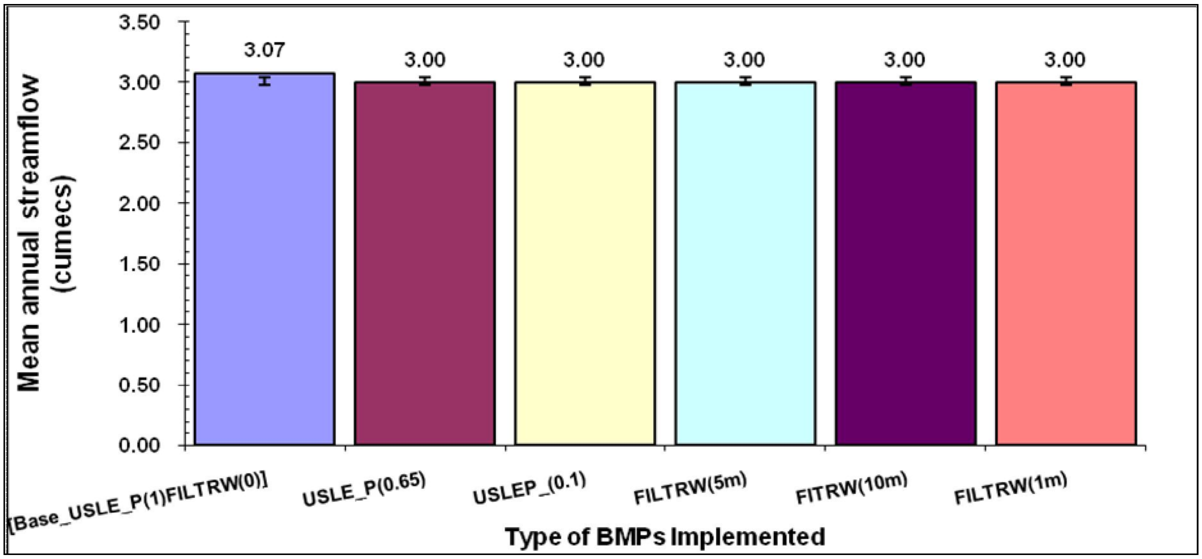

Figure 7: Impacts of BMPs on Streamflow at GETA area (Error bars with standard deviation)

These difference in results for Geta subbasin can be attributed to varying land slopes. In Geta, there are more steep slopes (>10%) compared to Wanjohi area. When the slopes exceed 10%, the effectiveness of filter strips and contour farming (contour tillage, strip cropping on the contour and terrace systems) are drastically reduced. This calls for introduction of more advanced conservation measures such as grade stabilization or bench terraces since contour farming practice applies on sloping land where crops are grown and is most effective on slopes between 2 and 10 percent.

Implementation of Best Management Practices (BMPs) is a conventional approach for controlling nonpoint sources of sediments and nutrients. However, implementation of BMPs is rarely followed by a good long-term data monitoring program in place to study how effective they have been in meeting their original goals. Long-term data on flow and water quality within watersheds, before and after placement of BMPs, is not generally available. Therefore, evaluation of BMPs (especially new ones that have had little or no history of use) must be necessarily conducted through watershed models.

4.1.2 Effects of BMPs on Sediment Yield

The simulated effect of filter strip and contour terrace on sediment output at the outlets of the two selcted areas are depicted in Figure 8 for Wanjohi sub-basin and Figure 9 for Geta Sub-basin respectively.

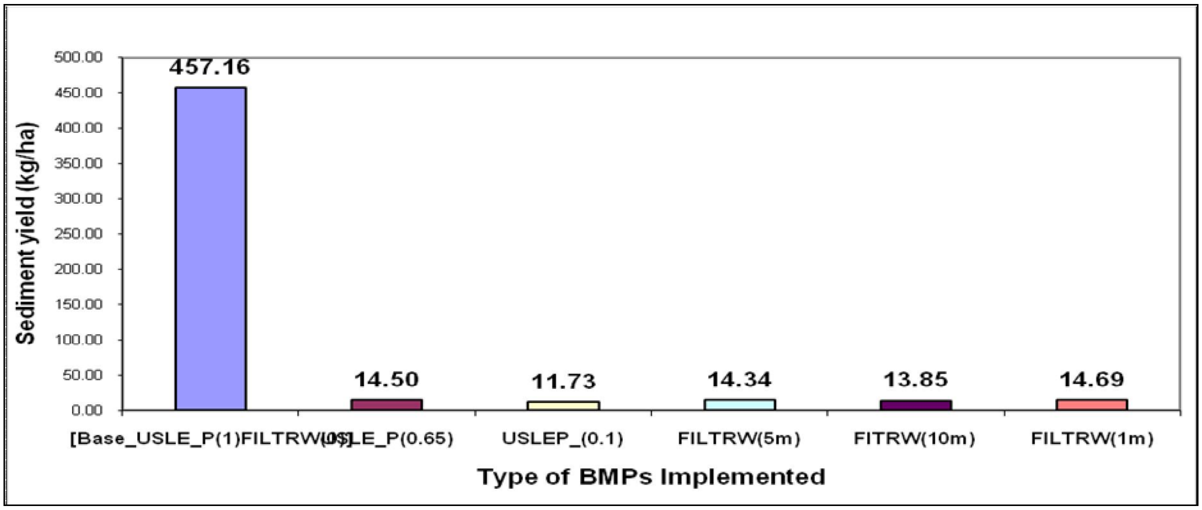

Figure 8: Impacts of BMPs on Sediments at Wanjohi area

The results show that the BMPs decreased the average monthly sediment yield at Wanjohi sub-basin outlet from 457.16 kg/ha (without BMPs) to 11.73 kg/ha for the best BMP (USLE_P=0.1 which is equivalent to contour terrace). Other BMPs had similar reductions ranging from 14.69 kg/ha for filter width of 1 m , 13.85 kg/ha for filter width of 10 m, 14.34 kg/ha for filter width of 5 m and 14.5 kg/ha for contour terrace with USLE_P value of 0.5. The introduction of filter strip had a significant effect in sediment yield reduction. Changing the filter strip from 5 m width to 10 m width had very little change on sediment yield reduction.

When BMPs are implemented in Geta Figure 9, there is a substantial decrease in sediment yield from 424.56 kg/ha with no BMPs to 18.9 kg/ha with contour terrace in place (USLE_P value of 0.50, 15.52 k/ha for contour terrace with USLE_P value of 0.1, 15.52 kg/ha, 18.74kg/ha and 19.08 kg/ha for filter widths of 5m, 10m and 1m respectively. The results show that sediment trapping efficiency improves with increasing buffer width.

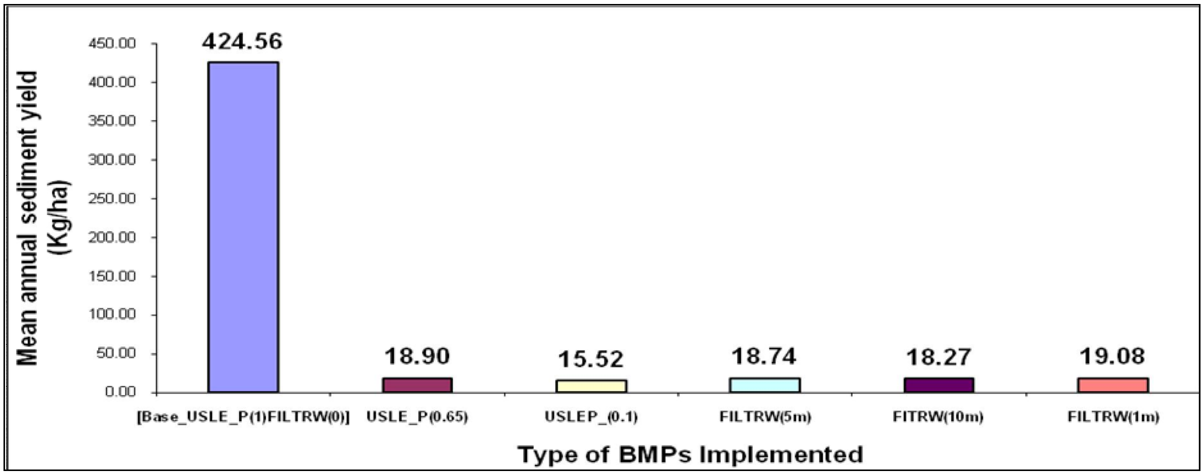

Figure 9: Impacts of BMPs on Sediments at GETA area

Further analysis was done to see the efficiency of the implemented BMPs. An overall evaluation was made by estimating BMP efficacy in terms of percentage reduction of the parameter (Equation 4.2):

$$\text{Reduction } (\%) = \frac{\text{Model output (Without BMPs)} - \text{Model output (With BMPs)}}{\text{Model output (Without BMPs)}}$$

Equation 4.2

The efficacy of the BMPs for abating sediment yield in the selected areas calculated using equation 4.2 is given in Table 5.

Table 5: The efficacy of BMPs simulated in the study sub-basin areas

		% Reductions				
Sub-basin	**Measured output**	**Contour terrace**	**Contour terrace**	**Filter width**	**Filter width10m**	**Filter width 1m**
Wanjohi	**FLOW_OUT**	-0.43	-3.31	-3.32	-3.32	-3.32
	SED_OUT	96.83	97.43	96.86	96.97	96.79
	ORGN_OUT	97.33	99.25	98.3	98.86	97.37
	ORGP_OUT	96.86	99.1	98.03	98.68	96.95
	NO3_OUT	91.9	91.84	92.29	92.68	92.05
Geta	**FLOW_OUT**	2.52	2.52	2.51	2.51	2.51
	SED_OUT	95.55	96.34	95.59	95.7	95.51
	ORGN_OUT	-21.87	64.63	24.04	49.17	-17.74
	ORGP_OUT	60.56	88.54	75.43	83.56	61.92
	NO3_OUT	99.07	99.06	99.18	99.28	99.11

Table 5 presents the efficacy results of implementing BMPS as percentage reductions in average annual sediment, total nitrogen (organic and mineral nitrogen) and total phosphorus (organic and mineral phosphorus) loadings at Geta and Wanjohi sub-basins outlets. The results indicate a significant reduction in sediment, total N and total P with implementation of BMPs. The decrease could be due to lesser sheet erosion from upland areas.

4.1.3 Effects of BMPs on Nutrient Yield

The results of the effects of BMPs on nutrient yield are presented as percentage reductions in average annual total nitrogen (organic and mineral nitrogen) and total phosphorus (organic and mineral phosphorus) loadings at the selected subbasins (Geta and Wanjohi). Loadings generated in the pre-BMP conditions were used as the base to estimate the percentage load reductions. Figure 10 and Figure 11 presents the results of the simulated total organic N yields at the Wanjohi and Geta outlets respectively.

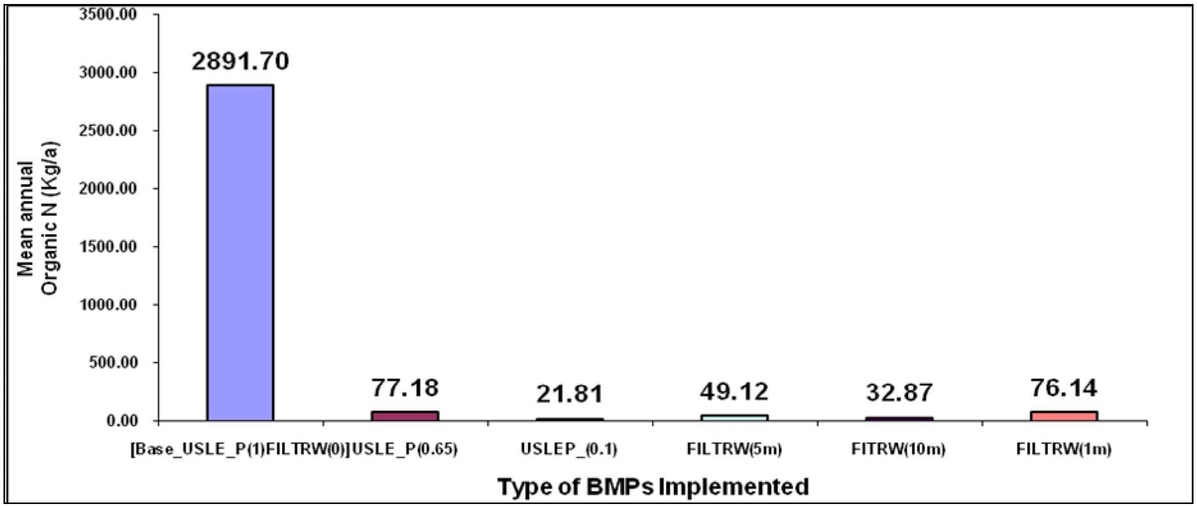

Figure 10: Impacts of BMPs on Organic N at Wanjohi area

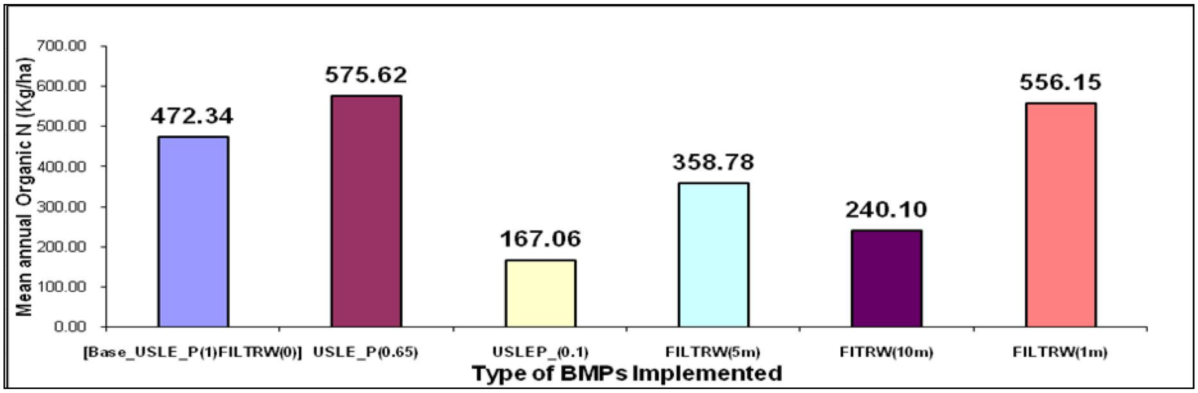

Figure 11: Impacts of BMPs on Organic N at Geta area

The results of installing BMPs in the watersheds indicates that without BMPs, total organic N yield predicted by the SWAT were 2891 Kg/ha for Wanjohi and 472 Kg/ha for Geta. After the implementation of the BMPs, there was a significant decrease in organic N in both sub-basins. The decrease for Wanjohi sub-basin was from 2891 kg/ha to 77.18, 21.81, 49.12, 32.87 and 76.14 kg/ha for contour terrace (USLE_P=0.5), contour terrace (USLE_P=0.1), and filter widths of 5m, 10, and 1m respectively. The decrease for Geta was from 472.34 kg/ha to 167.06 kg/ha for contour terrace (USLE_P=0.1) and 358.78kg/ha and 240.1kg/ha for filter width of 5m and 10m respectively. Contour terrace having USLE_P value of 0.5 and filter width of 1m were not effective in Geta sub-basin. The organic N increased from 472.34 in base conditions to 575.62 for USLE_P=0.5 and to 556.15kg/ha for filter width of 1m respectively. Filter strips are based on the filter strip's ability to trap sediment and nutrients based on the strip's width. The shorter the width, the lower the trapping efficiency is. In Geta sub-basin, the slopes are steep hence the ineffectiveness of the 1m width filter strip.

The results of the total P predictions of the model results for selected priority sub-basins with BMPs implemented are presented in Figure 12 for Wanjohi and Figure 13 for Geta.

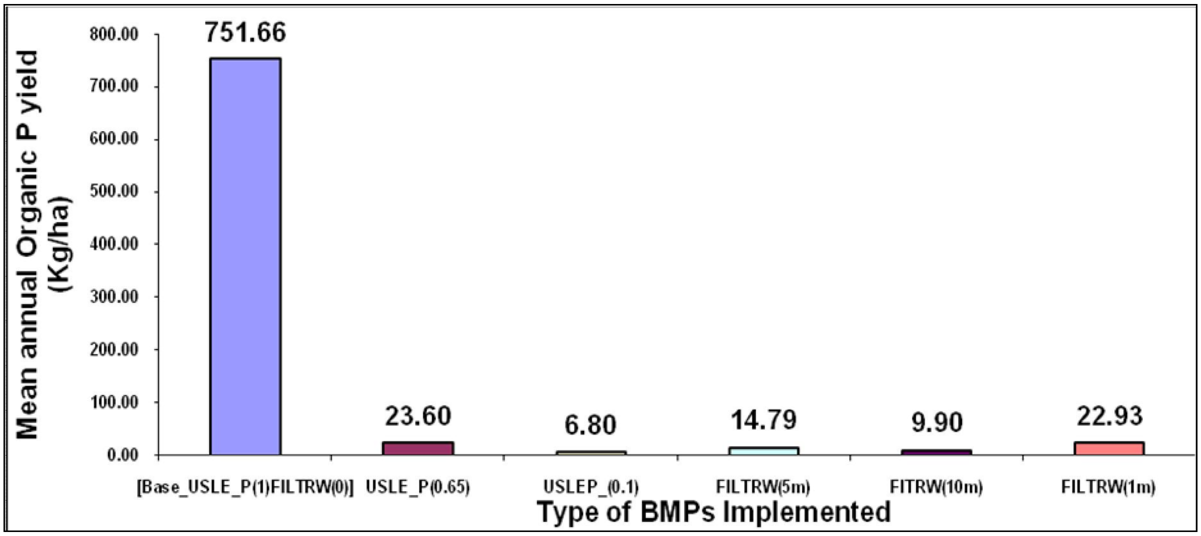

Figure 12: Impacts of BMPs on Organic P at Wanjohi outlet

The installed BMPs Figure 12 reduced the total P output from the sub- basins. For Wanjohi area, total P was reduced from 751.86 kg/ha to 23.6 kg/ha with contour terrace of USLE_P value 0.5and 6.8 kg/ha for contour terrace of USLE_P value of 0.1. The total phosphorous P values were also reduced with filter width put in-place. These reductions were as 14.79 kg/ha, 9.90kg/ha, and 22.93 kg/ha for filter widths of 5 m, 10 m and 1 m respectively.

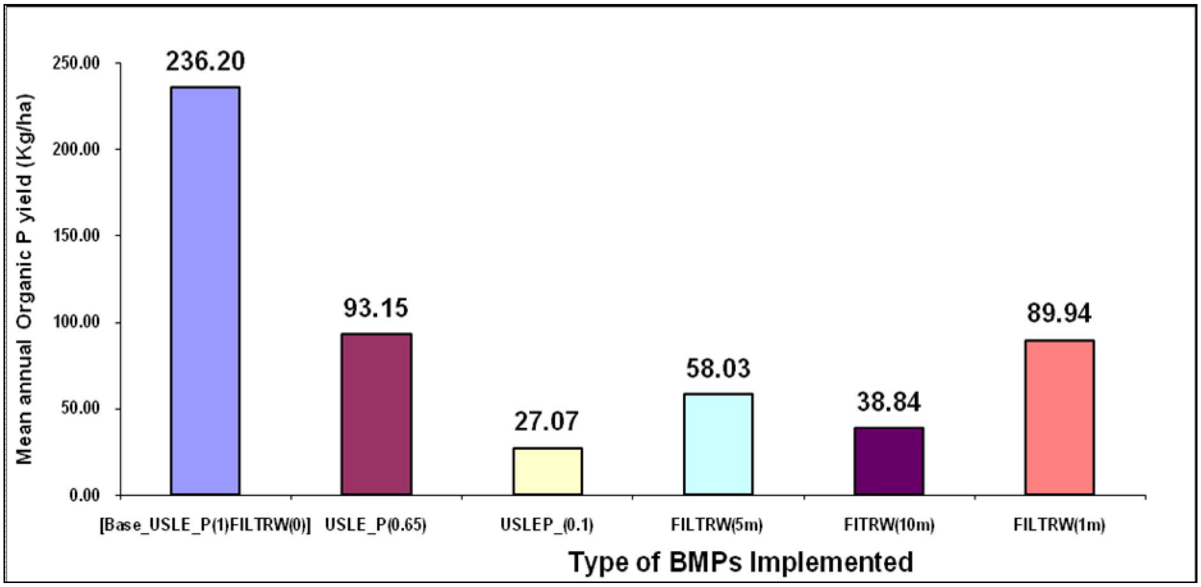

Figure 13: Impacts of BMPs on Organic P at Geta area

Figure 13 shows the results of impacts BMPs on organic P at Geta sub-basin outlet. The reductions were from 236.2kg/ha to 93.15kg/ha and 27.07kg/ha for contour terraces having USLE_P values of 0.5 and 0.1 respectively. The reduction of organic P achieved with filter widths of 5m, 10m, and 1m were as follows, 58.03kg.ha, 30.84kg/ha and 89.94 kg/ha respectively. The installed BMPs were estimated to effectively reduce N and P yields between 99-24% and 99-51% respectively (Table 5 for the two selected areas. It's worth noting that field border strip of 1 m and USLE_P of 0.5 were not effective in the Geta area. This is due to steep slopes found within the Geta sub-basin.

Most of the nutrients (total P, and total N) are introduced into the main channel and transported downstream through surface runoff and lateral subsurface flow. Major phosphorous sources are from mineral soil which include organic phosphorus available in humus, mineral phosphorus that is not soluble, and plant available phosphorus. Phosphorus may be added to the soil from agricultural lands in the form of fertilizer, manure, and residue application. Surface runoff is the major carrier of phosphorous out of most catchments (Sharpley and Syers, 1979). Major nitrogen sources in mineral soil include organic nitrogen available in humus, mineral nitrogen in soil colloids, and mineral nitrogen in solution. Nitrogen may be added to the soil from agricultural lands in the form of fertilizer, manure, or residue application. Plant uptake, denitrification, and volatilization, leaching, and soil erosion are the major mechanisms of nitrogen removal from a field. In the study area, soil erosion and leaching can be said to be the major mechanisms of nitrogen removal.

From the results of implementing BMPs, it can be noted that the reduction in total P load was consistent with the reduction of sediment yield at the outlet of the watersheds (Figure 8, Figure 9, Figure 12 and 13). This was anticipated for two reasons. First, in relatively small watersheds like Wanjohi and Geta, the role of in-stream nutrient processes that are simulated by SWAT, such as algal decay on phosphorus yield, is negligible compared to soil loss from upland areas and secondly due to channel erosion. In such watersheds, it can be claimed that sediment and nutrient yields are correlated. Moreover, the BMPs installed in the study watersheds were basically sediment control structures. The impact of the BMPs on nutrient loads was as a consequence of reduction of sediment yield. With installation of conservation structures such as filter strips, contour farming e.g. contour tillage, strip cropping on the contour and terrace systems, etc will enhance water quality coming from the upland areas of the catchment.

In summary, upstream land use practices have important impacts on water resources such as good water quality, less sediments, or more regular water flow for downstream users. However, much controversy exists about the direction and magnitude of such impacts. Payment for environmental services by downstream users to upstream users depends much on perceived and agreed upon mechanism for sharing of resulting benefits and costs by all recourse users in a watershed context. The study has focused on few management systems e.g. filter strips and contour farming systems that could be adopted in the study area in order to improve on the water quality and water flowing downstream. These management systems can be incorporated into the PES system which is a promising mechanism of improving the conditions of water resources in watersheds. For specific case of PES schemes in watersheds, the service usually relates to the maintenance of the availability and/or quality of water. The providers are upstream land users, whose land use is to be modified or conserved to render the service, and the users are downstream consumers – companies or individuals – of the water resources. For PES to have the desired effects they must reach land users in a way that motivates them to change their land use practices to more sustainable ones and for starting, the two management systems i.e. contour farming and 5m width filter strip will provide a beginning for implementation.

5.0 Conclusions and Recommendation

5.1 Conclusions

- The best management practices (BMPs) that were simulated in the selected sub-basins were represented in the model by altering corresponding model parameters. Model simulations were performed at various watershed subdivision levels. Comparisons of sediment and nutrient predictions with and without implementation of the BMPs were used to determine the efficiency of the BMPs at each watershed subdivision level. USLE support practice factor (USLE_P) accounts for the impacts of specific support practice on soil loss from a field. Support practices such as contour tillage, strip cropping on the contour, and terrace systems the default value for USLE_P is unity, this value was altered to 0.1, and 0.65 for the HRUs to implement the contour practice. The result shows that Filter strip and contours are effective in reducing the nutrient and sediment pollutant loads. Of the two best management practices simulated, filter strip offers the best alternative for reducing pollutant loads and should be encouraged for adoption by the upper catchment farmers.

- Filter strips were found to have varying effectiveness at reducing overland flow, sedimentation, and removing nutrients. The hydrologic benefit of riparian buffers increases with width.
- Considerable reductions in sediment concentrations occur when 5m wide filter strips are simulated. However, increasing the filter strips by an additional 5m (total 10 m) does not produce the same level of reductions as was observed for the 0 to 5m condition. This suggests that benefits from implementing filter strips will taper off for further increases in filter width.
- Reductions were slightly higher for sub-with moderate slope gradient compared to sub-basins with steep slopes. Also headwater sub-basins recorded greater reductions in sediment exports (e.g., 17, 13) compared to sub-basins located downstream (e.g., 23 and 19). Clearly greater improvements in water quality could be achieved by targeting headwater sub-basins.
- The impact of simulating filter strips on the sediment load at the main watershed outlet was also determined. The 5m filter scenarios produces a 17% reduction in sediment load, whereas doubling the filter widths only decreases the load by an additional 5%.

5.1 Recommendations

- There is need to do economic evaluation of BMPs on the Malewa watershed before embarking on their implementations and there is need to do further research on the best placement of the BMPs within the Malewa catchment.
- Implementing Best Management Practices (BMPs) in Malewa catchment will minimize the potential for agricultural nonpoint source water pollution and other adverse environmental and social problems. BMPs are practices based on the best available research and scientific data. They permit efficient farming operations while achieving the least possible adverse impact upon the environment or human, animal and plant health. Selection, design and implementation of appropriate BMPs require evaluation of resources involved, and the potential impacts on them. BMPs also require evaluation of the needs for sustainable agriculture, farm operations and markets and existing practices.

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